

THE TERTIARY IGNEOUS ROCKS OF THE
PAKOKKU DISTRICT AND THE SALINGYI
TOWNSHIP OF THE LOWER CHINDWIN DIS-
TRICT, BURMA, WITH SPECIAL REFERENCE
TO THE DETERMINATION OF THE FELSPARS
BY THE FEDOROFF METHOD

INAUGURALDISSERTATION

ZUR ERLANGUNG DER PHILOSOPHISCHEN DOKTORWÜRDE
VORGELEGT DER MATHEMATISCH-NATURWISSENSCHAFT-
LICHEN ABTEILUNG DER PHILOSOPHISCHEN FAKULTÄT DER
UNIVERSITÄT BASEL

VON

CECIL THOMAS BARBER

AUS BIRMINGHAM

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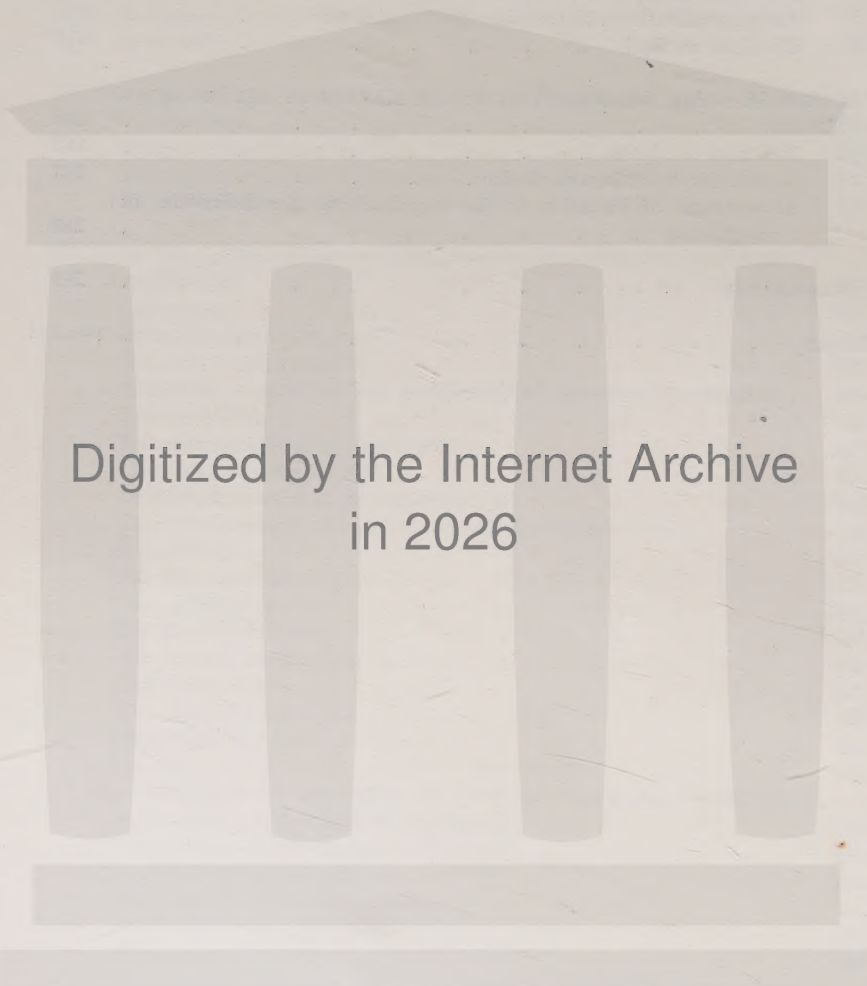
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PREFACE

This paper embodies an account of a suite of Tertiary igneous rocks in the Pakokku and Lower Chindwin districts of Burma which I mapped during the field-season 1925-26. As I was deputed to the post of Resident Government Geologist, at Yenangyaung, where I was fully occupied with oilfield problems, shortly after the completion of the field-work, I had no opportunity until I proceeded on leave in 1933 to make a systematic examination of the rocks collected. I have devoted the last eighteen months to their investigation which I have carried out in the Institute of Mineralogy and Petrology of the University of Basel, where, under the guidance of Professor M. Reinhard I have devoted special attention to the determination of the feldspars, and to a lesser degree of the mafic minerals by the Fedoroff method. As there are very few papers in English on this subject, and since it formed the greater part of my work at Basel, the question of Fedoroff determination has been discussed at considerable length.

The petrological investigation of the rocks has led to the modification of many of the tentative hypotheses formulated in the field, and what this paper has lost, in the form of graphic detail of the field occurrence of the rocks, owing to the lapse of time since they were mapped, it has more than gained in the form of systematic petrological treatment as a result of my studies at Basel.

In the course of my field-work, I enjoyed the benefit of discussion of many of the field problems with Dr. J. Coggin Brown, who, as Superintendent in charge of the Burma Party of the Geological Survey of India, visited me in the field and in the short space of ten days accompanied me to many of the important outcrops of igneous rocks. As my conclusions as to the age of some of these rocks differ from those of previous observers, I am grateful as much for the weight of his authority as for the most interesting time spent in his company. I am indebted to my colleague Mr. V. P. Sondhi for information relating to the basalt intrusion at Linzagyet and for completing the mapping of the Pegu-Alluvium boundary in sheet 84.N/4, and to Dr. P. Bearth of the Institute of Mineralogy and Petrology of the University of Basel, for the skill and care which he bestowed on the analysis of five of the rocks.

To Professor M. Reinhard, I am deeply indebted, not only for individual instruction in the methods of optical investigation, and particularly the Fedoroff method, which he himself has done so much to improve, but also for his unfailing interest in the whole of my work. The countless discussions with him of problems, both mineralogical and petrological, have immeasurably enriched my stores of knowledge and have illuminated many problems which would otherwise have remained obscure.

C. T. BARBER.

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CHAPTER I.

INTRODUCTORY.

The igneous rocks described in this paper lie between latitude 21° 30' N. and the North Yama Chaung (22° 7'), and occupy a narrow belt some fourteen miles in width to the west of the Chindwin river. Their position is shown in the topographical map given as Plate 24, from which it will be seen that they occupy a central position in the central Tertiary basin of Burma, which lies between the mountain range of the Arakan Yoma on the west and the elevated Shan plateau on the east, and extends from the Gulf of Martaban in the south to the Naga hills in the north. The broad geological features and geotectonics of this Tertiary basin have been described in a previous work¹, and my remarks on these subjects will therefore be confined to those aspects which are necessary for a proper appreciation of

¹ C. T. Barber, 'The Natural Gas Resources of Burma', *Mem. Geol. Surv. Ind.*, LXVI, pp. 1-172, (1935).

the geological age of the igneous rocks and their relationship to the tectonic history of the Tertiary era. For this purpose we may remind ourselves that the Tertiary rocks of Burma have been classified by the officers of the Geological Survey of India as:—

Eocene, the various sub-divisions of which are not relevant to the present work.

Pegu series, embracing the Lower and Upper Oligocene and the Lower and Middle Miocene.

Irrawaddy series, Pontian to Pliocene.

The early work of Mr. T. H. D. La Touche¹ in the Northern Shan States and the more recent work of Dr. J. Coggin Brown and Mr. V. P. Sondhi² in the Southern Shan States has shown that when the Tertiary sea extended over the central Tertiary basin of Burma the Shan plateau had already been elevated above its waters, while Dr. G. de P. Cotter³ has adduced evidence to show that at the commencement of the Tertiary era the Arakan Yoma existed as a low, narrow peninsula and formed during this era a continually rising geoanticline. The latter author believes that during this era the central Tertiary basin constituted a continually sinking geosyncline, and has elaborated the conception that this basin, called by Sir Edwin Pascoe⁴ the 'Pegu gulf', was gradually filled up from the north by the fluvial sediments of rivers, which, as Sir Edwin Pascoe⁵ states, may be regarded as the precursors of the modern Chindwin and Irrawaddy rivers. The result of this sedimentation, principally from the north, is that terrestrial conditions first made their appearance at the extreme north of the gulf, while marine conditions persisted longest in the south. Thus, while, as Dr. Cotter⁶ has shown by the discovery of Eocene mammalian remains at Myaing, Eocene land conditions existed in the north, the Eocene deposits of Lower Burma are typically marine. Similarly, the same observer has shown that the Oligocene and Miocene sediments of

¹ T. H. D. La Touche, 'Geology of the Northern Shan States', *op. cit.*, XXXIX, 309, (1913).

² General Report of the Geological Survey of India for 1929, 1930, 1931 and 1932, *Rec. Geol. Surv. Ind.*, LXIII, pp. 86-91 (1930); *op. cit.*, LXV, pp. 89-90 (1931); *op. cit.*, LXVI, pp. 98-104, (1932); *op. cit.*, LXVII, pp. 46-48, (1933).

³ G. de P. Cotter, 'The Geotectonics of the Tertiary Irrawaddy Basin', *Journ. As. Soc. Beng.*, New Series, XIV, (1918).

⁴ E. H. Pascoe, 'The Oilfields of Burma', *Mem. Geol. Surv. Ind.*, XL, p. 23, (1912).

⁵ E. H. Pascoe, *loc. cit.*, p. 252.

⁶ G. de P. Cotter, *loc. cit.*

Pakokku are freshwater or estuarine while in south Minbu they are of a more marine type, and in Thayetmyo district, still further south, are typically marine and yield a rich fauna of marine fossils. By the close of the Miocene period, terrestrial conditions had encroached as far south as the most southerly Tertiary rocks now exposed in Burma, but Pliocene and post-Pliocene marine sediments may be buried beneath the alluvium of the Irrawaddy delta, and marine sediments are still accumulating in the Gulf of Martaban.

The complete Tertiary succession is exposed in the foothills of the Arakan Yoma which are followed in an eastern direction by a broad syncline extending from Thayetmyo ($19^{\circ} 20' : 95^{\circ} 14'$) in the south, to beyond Yenau ($23^{\circ} 56' : 94^{\circ} 30'$) in the north and occupied by the freshwater sands and gravels of the Irrawaddy series. To the east of this syncline, Pegu and older rocks are exposed in a series of anticlinal structures, including the well-known oil-fields of Upper Burma, and which in this region may be classified as four main structural lines which are indicated in the map given as Plate 24 :—

- (a) Passing through the anticlinal structures of Ondwe ($20^{\circ} 6' : 95^{\circ} 11'$), Yenangyaung ($20^{\circ} 27' : 94^{\circ} 55'$), Singu ($20^{\circ} 56' : 94^{\circ} 51'$), Yenangyat ($21^{\circ} 6' : 94^{\circ} 48'$) and Bawdibin ($22^{\circ} 37' : 94^{\circ} 42'$).
- (b) Passing through the anticlinal structures of Yedwet ($20^{\circ} 26' : 95^{\circ} 16'$), Gwegyo ($20^{\circ} 48' : 95^{\circ} 1'$), Pagan ($21^{\circ} 10' : 94^{\circ} 52'$), Myaing ($21^{\circ} 36' : 94^{\circ} 53'$), and Medin ($22^{\circ} 29' : 94^{\circ} 49'$) and, according to Mr. A. E. Day¹, trending north of this point in a north-easterly direction to pass through the Pegu inlier of the Shwebo hills.
- (c) Passing through Mount Popa ($20^{\circ} 50' : 95^{\circ} 18'$), the Kabat ($21^{\circ} 4' : 95^{\circ} 18'$) and Shinmadaung ($21^{\circ} 34' : 95^{\circ} 6'$) anticlines, and, according to Mr. Day, 'When traced further north it passes to the east of the Shwebo hills into the Katha district and possibly includes the Volcanics of the Wuntho region'.
- (d) Passing through the Lebya ($21^{\circ} 0' : 95^{\circ} 33'$) and Taungtha ($21^{\circ} 17' : 95^{\circ} 26'$) anticlines and the Pegu inlier of Taunggya ($22^{\circ} 6' : 95^{\circ} 17'$).

¹ E. S. Pinfold, A. E. Day, L. D. Stamp and H. L. Chhibber, 'Late Tertiary Igneous Rocks of the Lower Chindwin Region, Burma'. *Trans. Min. Geol. Inst. Ind.*, XXI p. 150, (1927).

The igneous rocks described in this paper lie on the third of these structural lines, the trend of which has been continued southwards by Dr. H. L. Chhibber¹ to pass through the intrusive rocks of the Prome and Tharrawaddy districts and the volcanoes of Narcondam island and Barren island. In view of the coincidence of the igneous rocks with one of the main structural lines lying to the east of the Chindwin-Irrawaddy syncline, the age of the folding in the central Tertiary basin of Burma is of considerable interest. This is a subject on which there is still an absence of complete unanimity. Mr. G. E. Grimes² in the case of the Yenangyat anticline placed an unconformity between the Pegu and Irrawaddy series. This view was accepted by Mr. L. V. Dalton³ who postulated general movement at the close of the Miocene period with the concomitant folding of the Pegu before the deposition of the Irrawaddy series, resulting in an unconformity between the two series and local overlap of the latter. This view was partially accepted by Sir Edwin Pascoe⁴ as a possible explanation of discrepancies in thickness of the Pegu rocks on the western and eastern flanks of the Yenangyat and Minbu anticlines, but the hypothesis of pre-Irrawadian movement on the scale suggested by Dalton is clearly rejected by him. The hypothesis of general unconformity between the Pegu and Irrawaddy series is also opposed by Dr. G. de P. Cotter⁵ who attributes the discrepancies between the thickness of the Pegu rocks on the western and eastern flanks of the Yenangyat and Minbu structures to fault folding, and who adduces palaeontological evidence to show that the Tertiary basin was a continually sinking geosyncline until the close of the Pliocene period. Dr. L. D. Stamp⁶, however, believes that folding took place throughout the whole of the Tertiary era, and in a paper written in collaboration with him, Mr. A. E. Day⁷ states that along the Medin line of folding (structural line (b) of the above classification) the Irrawaddy series rests unconformably on Yaw shales (Uppermost Eocene) at Myaing, and on Pondaung sandstone (Upper Eocene) at Medin, while to the north in the Shwebo hills Pegu rocks rest unconformably on Pondaung sandstones.

¹ H. L. Chhibber, 'The Geology of Burma', London p. 287, (1934).

² G. E. Grimes, *Mem. Geol. Surv. Ind.*, XXVIII, p. 48, (1898).

³ L. V. Dalton, *Quart. Journ. Geol. Soc.*, LXIV, p. 642, (1908).

⁴ E. H. Pascoe, *loc. cit.*, p. 206.

⁵ G. de P. Cotter, *loc. cit.*, p. 409.

⁶ L. D. Stamp, *Geol. Mag.*, LXI, p. 486, (1922).

⁷ E. S. Pinfold, A. E. Day, L. D. Stamp and H. L. Chhibber, *loc. cit.*, p. 155.

Mr. G. W. Lepper¹ also subscribes to the hypothesis of pre-Irrawaddian folding, and, on palæontological grounds emphasises the importance of unconformities at the base of the Oligocene, in the Upper Oligocene, and between the Pegu and Irrawaddy series.

A comprehensive account of igneous activity in Burma has recently been given by Dr. H. L. Chhibber² in his work entitled, 'The Geology of Burma'. It is proposed,

Previous observers. therefore, to confine my remarks in this paper to the region mapped by myself and to the volcanic occurrences lying to the immediate north of this area. The first geological study of the latter area appears to have been made by Professor A. Buxtorf who visited this region in 1903, but no account of his researches was published until the specimens collected by him were described by Dr. P. Kelterborn³ in 1925. Meanwhile, a preliminary account of the area was given by Dr. R. D. Oldham⁴ who described ten or eleven 'explosion craters' situated on both banks of the Chindwin river near Shwezaye (22° 22': 95° 0'). Dr. Oldham also mentioned the cone-shaped hills of Letpandaung (22° 5': 95° 5') which he described as consisting of a 'hard cherty rock, not unlike some of the less typical jaspideous beds of the Bijawars' and which he regarded as being formed of pre-Tertiary rock. He mentions, also, the occurrence of volcanic ashes and lavas apparently interbedded with Pliocene sandstone west of the hill of Enjindaung (Ingyin Taung, 22° 6': 94° 58') which he described as being composed of massive Pliocene sandstone. My own work has confirmed the presence of andesites interbedded in the sediments of this area but since a rich Miocene fauna was collected by Dr. Coggin Brown and myself from rocks lying to the immediate north of and on the same line of strike as Ingyin Taung, it is clear that Dr. Oldham was mistaken in referring these rocks to the Pliocene.

Sir Edwin Pascoe's reference to the 'vents of Shinmadaung'⁵ (21° 34': 95° 6') appears to be the first published reference to the igneous rocks of the Pakokku district. They are again referred to

¹ G. W. Lepper, 'An Outline of the Geology of the Oil-bearing Regions of Burma and of Assam-Arakan.' World Petroleum Congress, London, (1933), Reprint No. 169, pp. 1-12.

² H. L. Chhibber, *loc. cit.*, pp. 286-507.

³ P. Kelterborn, *Eclogæ geologicæ Helvetiæ*, XIX, pp. 352-359, (1925).

⁴ R. D. Oldham, *Rec. Geol. Surv. Ind.*, XXXIV, pp. 137-147, (1906).

⁵ E. H. Pascoe, *loc. cit.*, p. 45.

by Dr. E. Vredenburg,¹ who, as a result of his investigation of *Ampullina birmanica* which occurs at the foot of Shinmadaung, refers the sediments of this area to the base of the Oligocene and states :—

‘Of particular interest, in the Shinmadaung area, are the contemporaneous volcanic intercalations towards the base of the Oligocene and towards the upper limit of the exposed strata’.

Dr. Vredenburg also states that in this area the lower Oligocene rests directly on pre-Cambrian schists. Neither of these conclusions is accepted by Messrs. Pinfold, Day, Stamp and Chhibber² who state that the igneous rocks appear to represent a period of specialised volcanic activity contemporaneous with the deposition of the basal beds of the Irrawaddy series, and who regard the fragments of metamorphic rocks, taken by Dr. Vredenburg for evidence of the exposure of the pre-Cambrian floor, as belonging to the Pondaung conglomerate (Upper Eocene), which, they state, contains similar boulders of igneous and metamorphic rocks in the Myaing and Medin inliers. In a later paragraph, I shall propose another tentative explanation of the occurrence of these metamorphic rocks and of the red clays with which they are associated. For the present, it is sufficient to say that I am prepared to accept, although I am not entirely convinced of its validity, the view that these rocks may be of Eocene age. If this is so, however, they are surely evidence of contemporaneous volcanic activity in Upper Eocene times, and not, as these authors suggest, merely in Irrawaddian times. In this connection it is interesting to note that these authors recognise the existence of contemporaneous volcanic activity in the Eocene of the Shwebo hills to the north.

The work of Messrs. Pinfold, Day, Stamp and Chhibber is concerned principally with the igneous rocks of the Twindaung area, lying to the immediate north of the area investigated by me, but the rocks of this area were also partially mapped by them and they recognised the occurrence of rhyolites and rhyolitic breccias at Letpandaung (22° 5' : 95° 5'), of andesites near Maukthayet (22° 7' : 94° 58'), of intrusive rocks near Salingyi (21° 58' : 95° 5'), a basalt intrusion at Linzagyet (21° 51' : 95° 5') and of rhyolites, basalts and intrusive rocks in the Shinmadaung area (21° 34' : 95° 6').

¹ E. Vredenburg, *Rec. Geol. Surv. Ind.*, LIII, pp. 359-369, (1922).

² E. S. Pinfold, A. E. Day, L. D. Stamp and H. L. Chhibber, *loc. cit.*, pp. 135 and 171.

An account of the igneous rocks of the Twindaung area has recently been given by Professor Conrad Burri and Dr. Hans Huber¹. These authors have given, in addition to an account of the field occurrence of these rocks, petrological descriptions of them and many analyses of great interest. Their conclusions will be referred to in the portion of this paper dealing with genetic problems.

¹ C. Burri and H. Huber, 'Geologie und Petrographie des jungvulkanischen Gebietes am Lower Chindwin (Upper Burma)'; *Schweiz. Min. Petr. Mitt.*, XII, pp. 286-343, (1932), and 'Grundzüge der Geologie von Burma mit besonderer Berücksichtigung des jungen Vulkanismus', *Zeitschr. Vulkan.*, XV, pp. 153-179, (1933).

CHAPTER II.

THE GEOLOGY OF THE REGION AND THE GEOGRAPHICAL DISTRIBUTION OF THE IGNEOUS ROCKS.

A geological map, on the scale of one inch to two miles, of the area under discussion is given as Plate 25. Apart from the igneous rocks, the following formations were mapped:—

The *recent alluvium* of the Chindwin river and its tributaries.

The *Irrawaddy series*, consisting of incoherent sands and gravels with rare intercalated clays, and containing abundant silicified fossil wood.

The *Pegu series*, consisting of rapidly alternating grey and blue clays and shales and soft false-bedded sandstones and, in the lowest horizons exposed, of massive sandstones which are locally sufficiently indurated and homogeneous to form a workable freestone.

In addition to these formations, surface deposits of 'Plateau Gravel'¹ and 'Plateau Red Earth'² are locally extensively developed, and in some instances obscure the relationship of the various igneous rocks to one another and to the surrounding sediments. These deposits are certainly of post-Tertiary age and are referred by Sir Edwin Pascoe to the Pleistocene. The similarity of the pebbles in the plateau gravels to those of conglomerates in the Irrawaddy series has led to the hypothesis that they have been formed by the denudation of the Irrawaddian, and represent a concentration of the coarse, indurated material brought about by the removal, by water and wind action, of the finer-grained material. The importance of wind action is evidenced by the polished surfaces frequently seen on the silicified fossil wood and more rarely by the occurrence of *dreikanter* among the pebbles of the Plateau Gravel. The red colour of the Plateau Red Earth is evidence of its sub-aerial origin, and Sir Edwin Pascoe has suggested that it was formed by the lateritisation of the Tertiary sediments and locally redistributed by the torrential rains which are characteristic of the

¹ E. H. Pascoe, *loc. cit.*, pp. 48-53.

² E. H. Pascoe, *loc. cit.*, pp. 50-53.

brief monsoon period in this region. The process of lateritisation of the Pegu sediments is one which is still taking place in this arid, dry zone of Upper Burma, and in recent excavations I have frequently traced a surface capping of red earth gradually merging with increasing depth into steeply-dipping sandy clays of the Pegu series, with a progressive change in colour from bright red at the surface to bluish-grey at a depth of from four to five feet.

In the southern portion of the area mapped, the boundary between the Pegu and Irrawaddy series is sharply defined and is one of profound unconformity, locally characterised by the development of a 'Red Bed'¹ representing an old land surface on which lateritisation of the Pegu sediments took place before the deposition of the Irrawaddian. The age of the Pegu sediments of this area has been established as Lower Oligocene by the discussion, by Dr. E. Vredenburg², of the zone fossil *Ampullina birmanica* which occurs at the foot of Shinmadaung (21° 34' : 95° 6'). Northwards, the boundary becomes less sharply defined and the unconformity less pronounced, till near Maukthayet (22° 7' : 94° 58') the Pegu sediments exposed are of Miocene age, as evidenced by a fauna collected by Dr. J. Coggin Brown and myself from this locality. Here, the Pegu-Irrawaddian boundary is obscured by the alluvium of the north Yama Chaung and its tributaries, but the mapping of my colleagues to the north and west indicates that this fauna was collected from very near the boundary between the two series. The examination by Mr. B. B. Gupta of the fauna collected from this locality has led to the identification of the following species :—

Gastropods	Casts of <i>Turritella</i> and <i>Cypræa</i> .
Echinoids	<i>Brissus</i> sp. allied to <i>B. declivis</i> , H. Cidarid spines.
Pelecypods	<i>Modiola affinis</i> , K. Mart. <i>Modiola</i> sp. <i>Pecten</i> sp. allied to <i>P. zitteli</i> , Fu. <i>Pecten</i> sp. <i>Ostrea</i> sp. <i>Lima protosquamosa</i> , Noetl.

¹ E. H. Pascoe, *loc. cit.*, pp. 29-31.

² E. Vredenburg, *loc. cit.*

Corals	<i>Stylophora digitata</i> , Pallas. <i>Calamophyllia</i> sp. <i>Leptoria</i> sp. <i>Hydnophoria</i> sp. ? <i>Favia</i> sp. <i>Orbicella defrancei</i> , E. & H. <i>Stylocænia tuberculata</i> , Greg. <i>Prionastræa lyonsi</i> , Greg. <i>Latimeandra</i> sp. <i>Pachyseris</i> sp. <i>Porites</i> sp. <i>Goniopora</i> sp.
Alcyonaria	<i>Isis compressa</i> , Dunc. <i>Isis</i> sp. 1, Dunc. <i>Isis</i> sp. cf. sp. 2, Dunc. <i>Isis</i> nov. spp.
Crustacea	<i>Balanus</i> sp. <i>Neptunus</i> sp.
Bryozoa	<i>Cellepora</i> . <i>Retepora</i> ?

Of the above species the following have been recorded from the localities mentioned, but with the exception of one or two species have not previously been recorded from the Miocene of Burma.

<i>Modiola affinis</i> , K. Mart.	Miocene, Java.
* <i>Pecten zitteli</i> , Fuchs.	Miocene, Java.
<i>Lima protosquamosa</i> , Noetl.	Miocene, Burma.
* <i>Brissus declivis</i> , Herklots	Miocene, Java.
<i>Stylophora digitata</i> , Pallas	Miocene, Java.
<i>Orbicella defrancei</i> , E. & H.	Miocene, Cosmopolitan.
<i>Stylocænia tuberculata</i> , Greg.	Miocene, Java.
<i>Prionastræa lyonsi</i> , Greg.	Miocene, Egypt.
<i>Isis</i> sp. 1, Dunc.	Miocene, India.
<i>Isis compressa</i> , Dunc.	Miocene, India.
* <i>Isis</i> sp. 2, Dunc.	Miocene, India.

Only forms allied to the species marked thus (*) have been identified in the Maukthayet collection, which, in addition to the species cited, appears to contain several new species that require further investigation.

Apart from the two fossil localities mentioned above, the Pegu sediments are for the most part barren and uninteresting and the

chief interest of the region centres in the occurrence of intrusive and extrusive rocks of Tertiary age. The latter fall naturally into four groups:—

- (A) The extrusive and intrusive rocks of the Shinmadaung area in sheet 84.O/2.
- (B) The intrusive and extrusive rocks of the Salingyi uplands and of Linzagyet in sheet 84.O/1.
- (C) The extrusive and intrusive rocks of the Ingyintaung and Powintaung area in sheet 84.J/16.
- (D) The Letpandaung and associated extrusive rocks of sheet 84.N/4.

The distribution of the one inch to one mile sheets referred to above is shown in the key to Plate 25.

CHAPTER III.

THE EXTRUSIVE AND INTRUSIVE ROCKS OF THE SHINMADAUNG AREA.

A geological map of this area on the scale of one inch to one mile is given as Plate 26. The chief topographical feature is the hill of Shinmadaung, rising to a height of 1,723 feet above ordnance datum and to over 1,000 feet above the general level of the surrounding country. It is composed of compact calcareous sandstones with rare intercalated shales, and on the western flank where it rises precipitously for over 800 feet, it is probably faulted. The crest of the hill swings round from S. S. W. by S. to N. N. W. and the strike of the rocks closely approximates to these directions. The eastern flank of the hill, an exaggerated dip slope, falls gradually away from the crest and the soil cap is here too thick to afford good exposures. East of the hill the country falls gradually to the Chindwin river, and, with the exception of an alluvial belt some three miles in width, is occupied by rocks of the Pegu series, consisting of clays, sandstones and sandy shales rapidly alternating both vertically and laterally. The structure is well brought out by a series of small scarps formed by thin compact sandstones capping softer clays and shales, a very typical topography of the dry zone of Burma, an example of which is illustrated by figure 1 of Plate 28, taken looking north from the village of Taungzindaw ($21^{\circ} 30' : 95^{\circ} 10'$). The strike conforms closely to the direction of the Shinmadaung arc, the dips radiating outwards from a centre situated some two and a half miles W. S. W. of the main Shinmadaung peak.

The general trend of the Shinmadaung range is continued in a N. N. W. direction through the somewhat lower peaks of Anyadaw ($21^{\circ} 39' : 95^{\circ} 5'$) and the hills south-east of the village of Taungu ($21^{\circ} 42' : 95^{\circ} 3'$), which are also composed of indurated sandstones with intercalated clays and shales. South-east of the village of Taungu itself, the sandstones are so homogeneous, and the bedding and jointing so regular, as to form a workable free-stone, and a flourishing industry in the manufacture of ornamental pagoda images has been established by the local inhabitants.

North-east of the Taungu hills, the Pegu sediments are not well exposed owing to an extensive development of Plateau Red Earth, and the solid geology is seen only where this has been dissected by recent denudation.

West of the Shinmadaung range, is a series of lesser but by no means inconspicuous hills occupying a narrow belt between the Shinmadaung escarpment and the Pegu-Irrawaddian boundary, a general view of which is given by the photograph comprising figure 1 of Plate 27. The names assigned to the various peaks shown in this photograph are those given, through an interpreter, by a cultivator from whose fields the photograph was taken. As far as I can gather, they are a matter of local association of ideas and events, and the inhabitants of other villages situated to the east of them know them in some instances by different names. As I have been unable to find a map on which they occur, their accuracy cannot be guaranteed, but, in conjunction with the photograph, they will serve to define the hills with greater precision than is otherwise possible on a map on the scale of one inch to one mile.

The broad, flat-topped hill of Sonetaung, situated east of the village of Tachanbe ($21^{\circ} 32' : 95^{\circ} 5'$), is composed of basalt in huge

The Sonetaung basalt. blocks piled upon one another to form a plateau one and a half miles long and approximately one mile in width. It rests on, and except on the north is surrounded by Pegu sediments, which in this area are of lower Oligocene age (*vide* page 129). In many places the edges of the plateau are precipitous and the absence of tumbled or residual blocks of basalt at the foot of the precipices suggests that it has been little modified by denudation. The whole flow has a remarkably recent appearance and locally a sub-parallel orientation of the blocks, indicating lines of flow is distinguishable. Generally speaking, these lines of flow are not traceable for more than a hundred yards and in places are not detectable at all, but they are more than usually prevalent towards the north of the plateau where they appear to radiate from a slight protuberance on the surface of the plateau, which is well seen (some distance south of the cone-shaped hill of Taungtha) in figure 1 of Plate 27. It is probable, therefore, that this represents the focus of eruption. Apart from the fact that it rests on Oligocene sediments, there is no positive evidence of the age of this flow, but I am inclined to agree with Mr. A. E.

Day,¹ who sees proof of its recent age, in the manner 'the blocks flow round local topographical summits—the flow descending into small valleys and piling itself up against summits which could not be overridden,' that it is probably of sub-recent origin. A petrological description of this basalt appears on pages 140-142, (micro-slides 24138-41).*

To the north of Sonetaung, rises the conspicuous cone-shaped hill of Taungtha (see figure 1 of Plate 27) which is composed of a compact, indurated volcanic ash. The texture of this rock is comparatively uniform but the colour varies from light grey to pale buff

The compact ash of Taungtha hill.

and both varieties contain small subrectangular aggregates, varying from one to two millimetres in length, of a white substance resembling kaolinised felspar. A specimen collected from near the summit of this hill contains elongated inclusions, composed of hematite, possibly with some silica, with pronounced rib structure on the weathered surface. These inclusions, which vary from one to seven centimetres in length and from three to eight millimetres in width, have the appearance of fossil wood but the fine structure seen in many specimens of fossil wood in the upper Tertiaries of Burma, is not recognisable. The petrological description of this rock will be found on page 142 (micro-slides 24142 and 24143).

The hills of Taungbet, Taungshe, Taunglungyi and Onebin, lying to the west of Shinmadaung (see figure 1 of Plate 27) and the hill of Taungle, situated one and a half miles S. S. E. of the village of Kabauk range.

(21° 36' : 95° 4'), are composed of coarse andesitic tuffs, with a local admixture of more acid pyroclastic rocks. These hills are remarkable for their cone-shaped form suggesting that each is a separate focus of eruption and the central portions of them are in some instances, as in the case of Taungle, formed of a tumultuous assemblage of blocks of glassy, scoriaceous lava locally somewhat rhyolitic and containing also pyroclastic material (slides 24144-5). The lower slopes of these hills, and two smaller hills situated between and slightly to the west of them, are formed of finer-grained tuffs of andesitic composition. From the petrological

¹ E. S. Pinfold, A. E. Day, L. D. Stamp and H. L. Chhibber, *loc. cit.*, p. 172.

* Registered numbers in the micro-slide collection of the Geological Survey of India, Calcutta.

descriptions of these rocks, given on pages 143 and 144 (micro-slides 24146-50), it will be seen that they consist of lithic tuffs containing, in addition to the volcanic material, consisting of felspar crystals, splinters of quartz, fragments of andesite and partially kaolinised volcanic glass, numerous fragments of metamorphic rocks.

North-east of the village of Tachanbe ($21^{\circ} 32' : 95^{\circ} 5'$) is an outcrop of bedded tuff extending from the village itself to the north-western margin of the Sonetaung basalt plateau. It varies considerably in texture and composition but three main types are recognisable. Towards its western margin it consists predominantly of lithic tuffs, greyish-white on the weathered surface and consisting of sub-angular fragments of many different rock types in a carbonate cement. On the newly-fractured surface, the rock is predominantly buff in colour but contains many fragments of dark grey and black lavas up to five millimetres in length, and with a pocket lens crystals of felspar are also visible. The rock affords a beautiful example of lustre mottling due to the carbonate cement being in crystallographic continuity (micro-slides 24151-2). The northern margin of the outcrop is also characterised by lithic tuffs, which here, however, are of much finer grain and contain a much higher percentage of metamorphic rocks than the specimens already described. They are compact, fine-grained rocks of arenaceous appearance and feel. Under a pocket lens, quartz grains are not recognisable as autonomous constituents and the rock is seen to consist of an assemblage of small angular fragments of much decomposed lava, some of which contain glistening felspar phenocrysts, and elongated lenticular fragments of dark schistose rocks (micro-slide 24153). Towards the east of the outcrop, crystal tuffs predominate. They are pale buff in colour and contain a great number of crystals of water-clear felspars, a few crystals of quartz and small fragments of lava, in a matrix of fine-grained feldspathic dust (micro-slides 24154-5).

At their western margin, these tuffs are overlain by thin-bedded sandstones of the Pegu series, and thin beds of similar tuffs are exposed in a stream section a quarter of a mile north of the village of Tachanbe, where they are interbedded with Pegu sandstones (see figure 2 of Plate 28). This occurrence of interbedded tuffs is situated immediately below the Pegu-Irrawaddian boundary, but,



FIG. 1.—Sketch profile along the line A—B of Plate 26, commencing one mile E. N. E. of Wagan and continuing to Gwebinya.

The small section, given above the main profile, is along a line parallel to and one mile to the north of the main profile, and illustrates the identity of the horizon of the interbedded tuff with that of the zone of *Ampullina birmanica*.

Horizontal scale 1" = 1 mile: Vertical scale $\times 4$.

I = Irrawaddy series: P = Pegu series: A = Andesite: B = Fine-grained Andesitic tuff: C = Coarse Andesitic tuff: D = Diabase: F = Zone of *Ampullina birmanica*: T = Interbedded tuff.

as mentioned above, the junction is here one of considerable unconformity and the Pegu sediments are of Oligocene age. A four-foot bed of similar tuffs is interbedded in the Pegu sediments at the south-western foot of Shinmadaung, where they dip E. N. E. by E. at 33° (micro-slides 24156-8). Here, their stratigraphical position is determinable with great precision since, as will be seen from text figure 1, they occur on the same line of strike as the zone fossil *Ampullina birmanica*, which was described by Dr. Vredenburg¹ from a locality lying half-a-mile to the north. They are, therefore, of Shwezetaw (Lower Oligocene) age.

Somewhat similar rocks occur in the small hill situated three quarters of a mile north-east of the village of Kabauk ($21^\circ 36' : 95^\circ 4'$) where they are interbedded with the Oligocene sediments at two horizons, and also capping the elongated ridge situated south-west of the village of Anyadaw ($21^\circ 39' : 95^\circ 5'$). At these localities the tuffs are finer grained than in the more southerly outcrops and, in contrast to the latter, contain a preponderance of sedimentary material and fragments of metamorphic rocks (slides 24159-62). It is considered that these features indicate that these more northerly outcrops lie further from the focus of eruption and also, probably, that the material has been sorted by subaqueous sedimentation, resulting in the elimination of much of the volcanic material and a concentration of the more resistant fragments of metamorphic rocks.

The low ground lying to the immediate south-west of the above-mentioned elongated outcrop of tuffs is occupied by an andesitic rock, weathering down to red, chocolate and

The andesites and associated rocks of the Shinmadaung area. ochreous clays. Occurring as they do at the Pegu-Irrawaddian boundary, these clays were originally taken for the 'Red Bed'² which frequently characterises this horizon, but subsequently residual spheroidal boulders of altered andesite were observed in this deposit in several stream-lets, and its true nature revealed. Similar clays resulting from the weathering of Tertiary basalts have been recorded by Dr. A. Harker³ and other observers in the northern and western parts

¹ E. Vredenburg, *loc. cit.*

² E. H. Pascoe, *loc. cit.*, pp. 29-31.

³ A. Harker, 'The Tertiary Igneous Rocks of Skye', *Mem. Geol. Surv. G. B.*, pp. 46-49, (1904).

of Skye, where they have been examined as a possible source of bauxite.

An outcrop of similar clays occurs three-quarters of a mile east of the village of Kabauk, where the residual nodules of andesitic rock are so decomposed as to render identification difficult. It is possible that part at least of this latter outcrop consists of andesitic tuffs, which, being of similar composition to the andesites, yield weathering products which are indistinguishable from those of the andesites themselves. In a cart track which traverses the southern margin of this outcrop, a compact rock of bright pistachio-green colour, locally stained by limonite, and containing large aggregates of somewhat smokey quartz, is exposed. The description of this rock (micro-slide 24163) will be found on page 148.

Andesitic weathering products, with occasional outcrops of comparatively fresh andesites (micro-slides 24164-70), surround the tuff cone of Taungle and occupy the low ground between and to the west of the hills of Onebin, Taunglugyi, Taungshe and Taungbet. Here also, the similarity between the weathering products of the andesites and the tuffs, renders the mapping of their boundaries uncertain, and their mutual relationships are still further obscured by alluvial areas of paddy land which occupy the lower ground.

In the valley between Shinmadaung and Taungnigyi, andesites are again poorly exposed and are associated towards their southern margin with an intrusive rock which I have described as a diabase (micro-slides 24171-2). In this region, the difficulties consequent on the advanced state of decomposition of the rocks are enhanced by the thickness of the soil cap and the denseness of the jungle, and the relationships of these rocks to one another and to the surrounding Pegu sediments are obscure. At one point, however, the contact between the andesite and the diabase is characterised by a narrow selvage of fine-grained rock which I have described under the name 'variolite' (micro-slides 24173-4).

There remains for consideration in the Shinmadaung area, the small area lying at the western foot of Taungtha, denoted as country rock in the geological map given as Plate 26.

Country rocks.

Here the surface is strewn with large boulders and small fragments of metamorphic rocks, consisting of quartz-sericite schists and albite-garnet-gneisses (micro-slides 24175-6). Since I was unable to find metamorphic rocks *in situ*, it is presumed

that it was the occurrence of these rocks which led Dr. Vredenburg¹ to postulate the exposure of the pre-Cambrian floor in this area. Messrs. Pinfold, Day, Stamp and Chhibber² were also unable to locate the old schistose floor in this area, and consider that these metamorphic rocks are boulders derived from the conglomerates of the Pondaung sandstone (Upper Eocene) which they state is exposed in this region. I was not aware of this hypothesis at the time of my field-work in this area, but the hypothesis which I formed at that time, and to which I still subscribe, is that these boulders and fragments represent material from the old crystalline floor, which all observers agree is probably very near the surface in this region, which were brought up by the paroxysmal activity of one of the volcanic vents from which the other pyroclastic rocks of this area were extruded. The rocks occurring in this outcrop are identical with the fragments of metamorphic rocks which occur in the lithic tuffs, in which they are mixed with varying percentages of volcanic rocks, and it is considered that these boulders and large fragments represent the coarsest material extruded, the finer particles being carried greater distances from the focus of eruption, where they were deposited, together with strictly volcanic material to form the tuffs above described. I do not exclude the possibility that, as suggested by Messrs. Pinfold, Day, Stamp and Chhibber, these rocks in their present state of aggregation may be of Pondaung (Upper Eocene) age, but, until palæontological evidence is forthcoming, I prefer to regard them as of Shwezetaung (Lower Oligocene) age. The same observers mention colour-banded clays which they also mapped as Pondaung in this region. Part, at least, of the Pondaung outcrop shown by them coincides with the outcrop of red, chocolate and ochreous clays in which I found residual boulders of andesite and which, on that basis, I have mapped as andesites. Again, I do not exclude the possibility that they may be of Pondaung age, but, whatever their age, they appear to me to afford conclusive evidence of contemporaneous volcanic activity.

Summarising the evidence as to the age of the igneous rocks of this area, it may be stated that the bedded tuffs are certainly of Lower Oligocene age. The relationship of the other pyroclastic rocks and of the andesites to the surrounding Pegu sediments are

The age of the igneous rocks of the Shinmadaung area.

¹ E. Vredenburg, *loc. cit.*, p. 365.

² E. S. Pinfold, A. E. Day, L. D. Stamp and H. L. Chhibber, *loc. cit.*, pp. 153-154.

by no means so clear, but they are so similar in composition to the bedded tuffs, in which fragments of andesite are abundant, that I consider that they should be regarded as being pene-contemporaneous with them. A possible exception is the ash cone of Taungtha hill which is different in texture and composition from the other pyroclastic rocks and to which the field evidence does not permit me to assign an age. It is flanked on the south by the basalt plateau of Sonetaung, in the case of which also there is no positive evidence of its age but which I believe to be the youngest of the igneous rocks of this region and possibly sub-recent.

Petrological description of the Igneous Rocks of the Shinma-daung area.

In the following descriptions of the micro-slides of the rocks described above, and in all the subsequent descriptions of micro-slides, the feldspars were determined by the Fedoroff method except where otherwise stated. Except where otherwise stated also, the optic angle of the other minerals was determined by this method. Where a value is given for the birefringence the thickness of the slide was determined by the direct method (the so-called Duc de Chaulnes' method).

The numbers assigned to the micro-slides are those given to them in the Geological Survey of India register of these sections.

(MICRO-SLIDES 24138-41.)

Basalt (Sonetaung).

A holocrystalline, porphyritic rock consisting of phenocrysts of olivine and diopside, together forming approximately thirty per cent. of the rock, in a microlitic groundmass, containing in addition to the bytownite microlites, small interstitial grains of olivine, pyroxene and magnetite. The average length of the olivine phenocrysts is one millimetre, as compared with 0.4 mm. in the case of the more numerous phenocrysts of diopside. The average length of the bytownite microlites is 0.15 mm.

The *olivine* phenocrysts include many crystals in which the idiomorphic contours are but little modified by corrosion. Apart from narrow reaction rims, the majority of the crystals are quite

fresh but a few show local alteration to *iddingsite* and comparatively rarely to *serpentine*, along irregular cracks. Several crystals show well-developed cleavage on (010) and a few also show cleavage on (100). Inclusions of small grains of ore are abundant. The optic angle of three specimens determined by the Fedoroff method is 90° and the maximum birefringence of the mineral is 0.037. According to Winchell,¹ these properties indicate chrysolite with a molecular percentage of 15 of Fe_2SiO_4 . One of the specimens determined in slide 24138 is twinned on (031) and one of the hemitropes shows well-developed cleavage on (010) while the other shows a less developed cleavage on (001).

Pale green *diopside* occurs in allotriomorphic phenocrysts. It is quite fresh and without recognisable pleochroism. The maximum birefringence is 0.025 and the optic angle and extinction of two specimens determined by the Fedoroff method 59° and 43° respectively. These properties indicate a composition of sixty per cent. diopside in the diopside-hedenbergite series.²

In addition to the phenocrysts of olivine and diopside there are a few pseudomorphs, after a porphyritic constituent, of a pale brown isotropic mineral of lower refractive index than *canada balsam*. The average length of these pseudomorphs which are subrectangular in form is 0.3 mm. Pseudomorphs of a similar nature were described by Sir L. L. Fermor³ in the basalts of Bhusawal and were designated by him as 'brown palagonite'.⁴

The felspar microlites are quite fresh and the composition of ten specimens lay between 75 and 90 per cent. anorthite. They included five examples of albite twinning, in two instances in association with pericline twinning; two of carlsbad twinning and two of polysynthetic carlsbad and albite twinning also in combination with pericline twinning. The remaining specimen was twinned according to the pericline law. Eight of the ten specimens determined showed well-developed cleavage on (001).

The groundmass contains, in addition to the felspar microlites, interstitial grains of olivine, pyroxene and ore. The grains of ore

¹ N. H. and A. N. Winchell, 'Elements of Optical Mineralogy,' Part 2, New York (1927), p. 168.

² *Vide* N. H. and A. N. Winchell, *loc. cit.*, p. 184.

³ L. L. Fermor, *Rec. Geol. Surv. Ind.*, LVIII, pp. 132-133, (1925).

⁴ For discussion of this use of the term palagonite, which is common in Indian literature, see description of micro-slide No. 24164 (page 149).

are black by reflected light and average less than 0.05 mm. in diameter.

In slides numbers 24140-1 which are somewhat vesicular, diopside phenocrysts are absent and the reaction borders shown by the olivine crystals are more pronounced than in slide 24138 and appear to consist of weathered iddingsite.

MICRO-SLIDES 24142-3.

Compact ash.

A fine-grained compact rock consisting of very fine volcanic dust, incompletely resolvable, even under high powers, and containing numerous pseudomorphs of kaolin and many fragments of transparent glass, which occur as elongated tubular bodies and as irregular fragments with pronounced concave surfaces, conferring upon the rock a very typical vitroclastic texture ('*Aschenstruktur*') which is illustrated by figure 1 of Plate 32. These particles of glass are partly kaolinised and, except by their form, are difficult to distinguish from the subrectangular pseudomorphs of kaolin after felspar, both in ordinary light and between crossed nicols. The latter vary from 0.3 to 0.8 mm. in length and in some instances contain in addition to kaolin, minute grains of quartz, occasionally arranged marginally. Many subrectangular holes in the slide are lined with a similar aggregate of minute quartz grains, the central portions of the pseudomorphs, consisting probably of friable kaolin, having been removed by the grinding process. The slide also contains a few irregular splinters of quartz, with an average length of 0.1 mm. and is traversed by elongated aggregates of hematite which are evidently correlative with the hematite aggregates seen in the hand specimen (*vide* page 134) and which are thought to be fossilised wood, but under the microscope no organic structure is recognisable.

MICRO-SLIDE 24144.

Rhyolitic tuff.

A glassy rhyolitic rock consisting predominantly of partially kaolinised brown glass, locally scoriaceous, and containing corroded quartz phenocrysts, a few subrectangular pseudomorphs of kaolin, and small splinters of colourless glass. The latter occur in

tubular and irregular bodies with concave outlines, which locally impart a vitroclastic texture to the rock. In addition to the corroded quartz phenocrysts, which have an average length of 0.3 mm., quartz also occurs in broken angular fragments which, combined with the splintery fragments of transparent glass, show that the rhyolite is contaminated with ashy or tuffaceous material.

MICRO-SLIDE 24145.

Rhyolitic breccia.

A glassy vesicular rock, with a suggestion of flow brecciation and containing numerous kaolin pseudomorphs after felspar phenocrysts.

The greater portion of the rock consists of dark brown opaque glass of higher refractive index than canada balsam, and, due probably to partial kaolinisation, very slightly birefringent. It contains irregular lenses of pale yellow kaolinised glass and numerous subrectangular pseudomorphs of kaolin after felspar phenocrysts. The latter, which average 0.3 mm. in length, are distinguishable from the pale yellow kaolinised glass only by their form, which is so regular as to leave little doubt that they are indeed pseudomorphs after felspar. The pale yellow kaolinised glass and to a lesser extent the dark brown glass are locally vesicular and many of the vesicles are partially filled by limonite. The dark brown glassy matrix also contains a few small grains and an aggregate of quartz, one millimetre in length.

MICRO-SLIDES 24146—8.

Andesitic tuffs.

Pyroclastic rocks consisting of dark brown volcanic glass, locally with a strong suggestion of flow structure, crowded with fragments of andesite, sandstone, quartz-sericite-schists and crystals of felspar (andesine).

The inclusions of andesite are of irregular shape but in contrast to those of schistose rocks, which are subrectangular, possess rounded outlines suggestive of minute lapillæ. Their diameter varies from 0.5 to 2 mm. and the length of the sandstone lenses and fragments of quartz-sericite schists also vary within these limits.

The felspar crystals vary from 0.3 to 1 mm. in length and are all of higher refractive index than the glassy matrix, which itself has a refractive index higher than canada balsam. Five specimens determined showed a range of anorthite content from 35 to 40 per cent. Two were slightly zoned, in one case the margin, and in the other the core being of slightly more acid composition.

MICRO-SLIDES 24149—50.

Andesitic tuff.

These slides are similar to those previously described except that felspar crystals are absent, but the glassy matrix contains irregular pseudomorphs of kaolin, somewhat stained by limonite, which may possibly be after felspar crystals or fragments. A few small splinters of quartz are present, and in slide 24150 there is a fragment of quartz-sericite schist 8 mm. in length and 1.5 mm. in width, which contains a few small needles of green tourmaline.

MICRO-SLIDES 24151—2.

Lithic tuff.

Under the microscope, this rock is seen to be a veritable petrological collection, containing fragments of all the igneous rocks recognised in the Shinmataung area with the exception of the basalt. Apart from the great variety of the fragments of which it is composed, the most remarkable feature of the rock is the intense pseudo-pleochroism of the carbonate cement, which over large areas of the slides is in optical continuity even where there is no visible morphological continuity. The pseudo-pleochroism is from colourless ($n\alpha$) to very dark grey, almost black ($n\gamma$), and the extremes of absorption coincide with the extinction.

Among the fragments of rocks present, andesite and variolite are the most numerous. They vary in diameter from 0.8 to 5 mm. and the larger fragments are subangular while the smaller usually show rounded contours. The variolite fragments are characterised by the presence of skeleton crystals of felspar and arborescent and radial growths of felspar crystallites, and except for the absence of epidote, bear a strong resemblance to the variolite described below (slides 24173—4) which was collected from the outcrop of

this rock. The slide contains also fragments of rhyolite with perlitic texture, vitrophyric tuffs, sandstone and quartz-sericite-schists, some with epidote, and numerous crystals of feldspar. The latter, which average 0.5 mm. in length are remarkably fresh, but a few are fractured. Many are characterised by zoning and the composition of five specimens determined by the Fedoroff method ranged from 35 to 60 per cent. anorthite. Phenocrysts of similar feldspars occur in some of the andesite fragments, where, however, they are by no means so fresh, but the specimens determined are embedded in the carbonate cement and not associated with lava fragments. The slides contain also a few fractured quartz crystals which also occur surrounded by the carbonate cement.

A micro-photo of this rock is given as figure 2 of Plate 32.

MICRO-SLIDE 24153.

Lithic tuff.

This is a compact fine-grained, clastic rock, fawn in colour and of arenaceous appearance and feel. Under a pocket lens, however, quartz grains are not recognisable as autonomous constituents and the rock is seen to consist of an assemblage of small subangular fragments of much-decomposed lava, some of which contain glistening feldspar phenocrysts, and elongated lenticular fragments of dark rocks of schistose appearance.

In thin section it is seen to consist of a chaotic assemblage of angular and subangular fragments of many different rocks of igneous, hydrothermal and sedimentary origin. The average grain size is approximately 1.5 mm.

Conspicuous among the rock fragments are andesitic rocks containing zoned and palagonitised feldspar phenocrysts, averaging 0.4 mm. in length, and palagonitised and chloritised ferromagnesian minerals, and finer grained microlitic andesitic rocks. The other igneous rocks are fragments of partially kaolinised brown glass, some containing kaolinised feldspar phenocrysts, such as characterise the rhyolitic tuffs already described. These igneous rocks together form approximately forty per cent. of the rock. The most important of the other constituents are quartz-sericite-schists, quartz-schists with garnets, quartz-epidote-sericite-zoisite-schists and quartz-epidote-rocks of hydrothermal origin. The latter are similar to the quartz-epidote-rock occurring *in situ* south-east of the village

of Kabauk (slide 24163) and the schists to those described from the foot of Taungtha Hill (slides 24175—76).

The slide also contains one aggregate, one millimetre in diameter, of banded chalcedony, but since this is almost completely isolated by the removal of the surrounding material during grinding, it is difficult to determine whether this was incorporated in the rock as an original constituent, or whether it is due to secondary silicification.

An apparently autonomous constituent is a crystal of epidote 0.4 mm. in length but its presence may be connected with the intense hydrothermal alteration which is shown by the andesite fragments.

MICRO-SLIDES 24154—55.

Crystal tuff.

A heterogeneous compact rock of pale buff colour containing many small crystals of water-clear feldspar, a few crystals of quartz and small fragments of lava, in a fine-grained matrix of feldspathic dust.

Under the microscope, the heterogeneous nature of the rock is still more conspicuous than in the hand specimen. The greater portion of the slides consists of a chaotic assemblage of clear feldspar crystals, many of which are broken, and small irregular and rounded fragments of andesitic lava and of dark brown rhyolitic glass, in a matrix of irresolvable dust. In these portions of the slides the feldspar crystals and fragments of lava together form approximately fifty per cent. of the rock but there are other portions in which feldspar crystals and recognisable rock fragments occupy less than five per cent. of the field (2.3 mm. in diameter).

Many of the feldspar crystals are conspicuously zoned and the composition of five specimens determined ranged from 35 to 60 per cent. anorthite.

In addition to the components already mentioned, slide 24154 contains one angular fragment of quartz-sericite schist, one millimetre in length, several aggregates of carbonate with radial structure and locally with very strong pseudo-pleochroism, from pale brown to very dark grey, and one fragment, 0.5 mm. in length, consisting of an intimate mixture of limonite and cryptocrystalline silica with a cellular structure very strongly resembling sclerenchymatic cells of vegetable matter.

MICRO-SLIDES 24156—8.

Tuffs.

These include much decomposed pyroclastic rocks consisting of a chaotic assemblage of kaolinised feldspars and subangular fragments of other pyroclastic rocks, with a carbonate cement, and showing some evidence of secondary silicification.

Parts of the slides are so stained by limonite that their original nature is unrecognisable. Among the recognisable constituents are pseudomorphs of kaolin, sometimes enclosing irregular aggregates of carbonate, with the form of idiomorphic feldspars. Such pseudomorphs occur isolated from other rock fragments by carbonate cement suggesting that they are autonomous constituents of the rock and the perfect idiomorphic form of some examples suggests that they were incorporated in the rock before kaolinisation took place. The association of carbonate with kaolin suggests further an appreciable anorthite content in the original feldspar.

Similar pseudomorphs of kaolin after feldspar, but with less perfect idiomorphic form, occur also in large subangular fragments, varying from two to six millimetres in length, of a rock in which they are the only identifiable constituents, the matrix being so stained by limonite as to render the recognition of its original nature impossible. The slides also contain small rounded fragments of andesite, also much stained by iron, and fragments of grey, partially kaolinised glass also containing in some instances pseudomorphs of kaolin after feldspars. Other fragments of similar light grey kaolinised glass contain amygdules of cryptocrystalline and crystalline silica.

MICRO-SLIDES 24159—62.

Lithic tuffs (or tuffites).

These rocks, consisting of chaotic assemblages of many different rocks are similar to the fine-grained lithic tuff described above (micro-slide 24153), but contain diminishing proportions of volcanic material and increasing proportions of angular fragments of country rocks. The igneous constituents, on which the principal evidence of their pyroclastic origin rests, are irregular fragments of kaolinised volcanic glass, and very few fragments of much altered andesite. The great bulk of the slides consists of angular and subangular

fragments of many different schistose rocks, and a few lenticular fragments of fine-grained sandstones.

It is thought that the impoverishment of these rocks in volcanic material may be partly due to re-sorting of the material of an original tuff cone or bank by denudation and sedimentation, in which process the less resistant volcanic rocks suffered comminution and destruction, resulting in the concentration of the more resistant country rocks.

MICRO-SLIDE 24163.

Quartz-epidote-rock.

This is a compact rock of bright pistachio-green colour, locally stained by limonite and containing large aggregates of somewhat milky quartz.

In thin section the rock is seen to consist exclusively of epidote and quartz, the former mineral predominating in the ratio of approximately six to four.

The *epidote* is very strongly pleochroic from colourless ($n\alpha$) to yellow ($n\beta$) and greenish-yellow ($n\gamma$). The optical angle (estimated) is -70° , the extinction $n\gamma \wedge (001) 28^\circ$, and the maximum birefringence 0.043. These properties indicate an iron rich member of the epidote series. It occurs in felted aggregates of slender prismatic crystals some of which attain a length of three millimetres, and some of which project into the aggregates of quartz which are enclosed by the epidote aggregates.

Quartz occurs in aggregates of large crystals, some of which attain a diameter of four millimetres. They show pronounced strain polarisation and are crowded with minute inclusions of a colourless transparent mineral of lower refractive index than the host. Owing to their minute size, their thickness being insufficient to affect the birefringence of the host, further determination is impossible. The quartz also contains, apart from the needles of epidote which project into it from the margin of the surrounding epidote, a few isolated minute prisms of this mineral.

MICRO-SLIDE 24164.

Altered andesite.

This is a porphyritic rock composed of much altered phenocrysts of felspar (labradorite) and pseudomorphs after a ferromagnesian mineral, together forming approximately forty per cent. of the

rock, in a hyalopilitic groundmass consisting of felspar microlites in abundant opaque glass, containing also a number of irregular grains of ore.

The *pseudomorphs after a ferromagnesian mineral* consist of a brownish-yellow fibrous mineral, with moderate positive relief, positive elongation, straight extinction and with low birefringence. It is faintly pleochroic from yellowish-brown with a faint suggestion of green (normal to the fibres) to a slightly darker orange-brown (parallel to the fibres). This substance appears identical with that described by Sir L. L. Fermor¹ as brown *palagonite* and which has been shown by him² and by Wadia³ and Chhibber⁴ to be formed by the hydrothermal alteration of ferromagnesian minerals and at the expense of felspar by replacement. As a result of a thorough investigation of the subject, Sir L. L. Fermor states:—

‘From the above one feels compelled to accept the existence of a series of secondary products of which the lighter coloured forms of lower refractive index are chlorophaeite. The term “brown palagonite” may then be restricted to the darker and often less pure forms of higher refractive index,’ and - - -

‘From the foregoing notes we see that under palagonite have been comprised at least two distinct substances. Treated generally, palagonite may perhaps be regarded as a hydrous glassy substance of variable composition formed partly by hydration of the primary glass and partly at the expense of augite (? again largely by hydration) and iron-ore, and with much more difficulty at the expense of felspar (? by replacement). In colour it ranges through orange and brown to brownish green, and the material of all colours may become “devitrified” and anisotropic, in spherulites and concentric-radiate layers, with in all cases a positive elongation to the fibres. The clear orange and brown varieties, both isotropic and anisotropic constitute chlorophaeite, whilst the anisotropic green form is probably identical with delessite or celadonite.’

The mineral forming the pseudomorphs under discussion is the darker and more highly refringent variety of brown palagonite which Sir L. L. Fermor⁵ has suggested may be an iron-rich variety of chlorophaeite. The pseudomorphs which have the form and cracks typical of rhombic pyroxene or olivine, form approximately

¹ L. L. Fermor, ‘On the Basaltic Lavas Penetrated by the Deep Boring for Coal at Bhusawal, Bombay Presidency’. *Rec. Geol. Surv. Ind.*, LVIII, pp. 132-133, (1925).

² L. L. Fermor and C. S. Fox, ‘The Deccan Trap Flows of Linga, Chindwara District, Central Provinces’. *Op. cit.*, LXVII, p. 81, (1916).

³ D. N. Wadia, ‘Palagonite Bearing Dolerite from Nagpur. Suggestion Regarding the Nature and Origin of Palagonite’. *Op. cit.*, LVII, pp. 338-343, (1925). pp. 338-343.

⁴ H. L. Chhibber, ‘Some Intrusive Rocks of the Pegu Yoma, Burma’. *Trans. Min. Geol. Inst. Ind.*, Vol. XXI, pp. 338-363, (1927).

⁵ *Rec. Geol. Surv. Ind.*, LVIII, p. 131, (1925).

ten per cent. of the slide. The original ferromagnesian mineral is entirely replaced, the fibres of the secondary mineral being arranged longitudinally.

The same secondary mineral has in many cases almost entirely replaced the felspar phenocrysts, and the slide furnishes many examples in which the core of the felspar is completely replaced by this mineral, leaving only a narrow, regular border of clear felspar. In one large phenocryst, in which the core is replaced by this mineral, concentric outer zones of little-altered felspar alternate with zones almost completely replaced by carbonate. Almost without exception, the portions of the felspar replaced by brown palagonite have the same contour as the felspars, which are idiomorphically developed. It is clear, therefore, that certain zones have been replaced and, since it is most frequently the core which is replaced, the presumption is that the more basic portions have been attacked by solutions rich in magnesium and iron, derived from the solution of ferromagnesian constituents, leaving the more acid margins intact. The pseudomorphs replacing felspar are readily distinguished from those replacing ferromagnesian minerals, not only by their characteristic triclinic form, but also by the fact that even when the felspar is almost completely replaced there remains a very narrow border of clear felspar. Whether, however, the narrow margin of clear felspar is in such cases really a remnant of the original felspar which has remained unaltered, or is a secondary growth of more acid felspar, is a moot question. Another distinction between the palagonite replacing ferromagnesian minerals and that replacing felspars is that in the latter the fibres are not regularly arranged. In some instances there is a tendency to radial arrangement, but in others, the orientation of the fibres is quite promiscuous.

Other felspars are altered to an imperfectly individualised mixture of brown palagonite with a predominance of carbonates and slight admixture of other unidentifiable secondary products, and not a single unaltered phenocryst and very few unaltered microlites remain. Remnants of four phenocrysts determined by the Fedoroff method showed a range of composition of from fifty to sixty per cent. anorthite, but since it is probable that these unaltered remnants represent the most acid portions, this composition cannot be regarded as representative of the original phenocrysts as a whole. The average length of the felspar phenocrysts is slightly over one

millimetre and of the microlites, which in their altered condition are too small for determination, 0.15 mm.

The groundmass consists of almost equal proportions of opaque glass and felspar microlites, and contains many small grains of a black opaque mineral, which, when viewed by reflected light, is seen to be mottled with white flecks. The largest of these grains is 0.2 mm. in diameter, but the average is not more than 0.05 mm.

MICRO-SLIDES 24165—70.

Altered andesites.

These are fine-grained compact rocks showing varying degrees of hydrothermal alteration and consisting of altered phenocrysts of plagioclase (andesine-labradorite) and pseudomorphs of chlorite, palagonite and carbonate in a pilotaxitic groundmass containing, in addition to the felspar microlites, numerous small grains of ore.

The *felspar* phenocrysts, forming approximately twenty per cent. of the rock, vary from 0.5 to 2.5 mm. in length, the average being slightly less than one millimetre. Fresh specimens are extremely rare, the majority showing advanced replacement by carbonate. In a few cases this replacement is irregular, but in the great majority it has taken place zonally, showing that zones of a particular composition, probably the most basic, have been most readily attacked. A remarkable feature of one large phenocryst, 2.5 mm. in length, which shows a regular marginal replacement by calcite combined with irregular internal replacement, is that the whole of the carbonate is in optical continuity, although many of the internal patches of calcite are connected with the marginal development of this mineral and with one another only by minute capillaries, now filled by calcite, along the (001) cleavage. Remnants of five specimens, determined in slide 24165, showed a range of composition from 45 to 50 per cent. anorthite, but since it is extremely probable that it is the more basic zones which have been replaced by carbonate, these determinations indicate a composition more acid than the average composition of the original felspars. The specimens determined include one example of albite twinning in combination with acline twinning, two of polysynthetic albite and carlsbad twinning and two of polysynthetic albite and complex albite-carlsbad twinning. Cleavage on (001) was well developed in only one of the five individuals.

Pseudomorphs of fibrous *chlorite*, pleochroic from very pale yellow ($n\alpha$) to greenish-yellow ($n\gamma$) are abundant. They are sub-rectangular in form and average 0.2 mm. in length. No trace of the original mineral remains but the form suggests that the pseudomorphs are after augite.

Other pseudomorphs, usually of irregular form, consist of aggregates of greenish-brown palagonite, frequently associated with calcite and ore. There are also a few subrectangular pseudomorphs consisting entirely of carbonate, apparently after feldspar phenocrysts.

Small grains of a *black opaque mineral*, mottled with white specks, occur both in the groundmass and associated with the chloritic and palagonitic pseudomorphs.

The feldspar microlites average 0.1 mm. in length. They are for the most part less altered than the feldspar phenocrysts but some are partially replaced by carbonate.

The margin of slide 24167 shows a contact between andesite and tuff with an infiltration of carbonate along the contact. The tuff consists of angular fragments of andesite, fine-grained sandstones, and crystals of quartz with some epidote and much carbonate.

Slide 24169 is slightly vesicular and contains also a few small aggregates of secondary quartz, while the groundmass of slide 24170 is so intensely altered to a structureless mass of opaque limonite that its original nature is no longer recognisable.

MICRO-SLIDES 24171—2.

Diabase.

This is a very decomposed holocrystalline rock of a pale green colour and much stained by limonite. Feldspars and a green fibrous mineral are alone recognisable under a pocket lens.

Microscopically it is seen as a holocrystalline rock of hypidiomorphic-granular texture, and consisting of plagioclase (andesine), pyroxene, much altered hornblende, abundant chlorite (penninite), and a little epidote and ore. Feldspar predominates slightly over the mafic minerals and the average grain size is 0.6 mm.

The *feldspars* are characterised by zoning but owing to advanced saussuritisation, complete determination of the zonal sequence in individual specimens was impracticable. The composition of four

specimens determined ranged from 35 to 50 per cent. anorthite. They are characterised by polysynthetic twinning and in the four specimens determined the following laws are realised:—albite in combination with pericline and baveno (rt.), albite in combination with complex albite-carlsbad and pericline, albite in combination with pericline, and polysynthetic carlsbad twinning. Two of the specimens showed well-developed cleavage on (001).

The *pyroxene*, where fresh, is colourless but it shows local alteration to chlorite and in one or two instances a marginal alteration to uraltite. The following optical data were obtained from five fresh specimens determined by the Fedoroff method:— $2V+52^{\circ}$ to 53° , extinction $n\gamma \wedge C$ 36° to 37° , which, with a maximum birefringence of 0.025, indicates a composition of 70 to 80 per cent. diopside in the clinoenstatite-diopside series.¹

Hornblende occurs in frayed crystals, in some instances clearly pseudomorphous after pyroxene but too much chloritised for optical determination.

Chlorite, pleochroic from pale yellow ($n\alpha$) to pale green ($n\gamma$) and polarising in the abnormal blue interference tint characteristic of penninite, is abundant in fibrous subrectangular aggregates averaging 0.6 mm. in length. It is uniaxial, optically negative, and has positive elongation. Their form suggests that these aggregates are pseudomorphs after hornblende.

Aggregates of hematite, apparently pseudomorphous after ferromagnesian minerals and associated with both epidote and chlorite are numerous and in two instances attain a length of 1.5 mm. The epidote is locally characterised by variations in the absorption colour in peculiar reddish-brown tints, which however, are thought to be due to its lamellar structure rather than to true pleochroism.

MICRO-SLIDES 24173—4.

Variolite.

This is a fine-grained compact rock of pale green colour traversed by granular veinlets of calcite. With a pocket lens, thread-like bodies of a colourless mineral are visible in a compact irresolvable matrix.

Under the microscope the rock is seen to consist of *epidote* and *felspar* with a little *chlorite* and veinlets of *calcite*, and the thread-

¹ Vide N. H. and A. N. Winchell, *loc. cit.*, p. 182.

like bodies seen under the lens are revealed as extremely elongated skeleton crystals of feldspar which are illustrated by figure 1 of Plate 33. In rare instances the latter reach a length of two millimetres but their breadth is less than 0.05 mm. These and smaller skeleton crystals are frequently slightly curved and swallow-tail terminations are common. Other common forms are hollow rectangular and H-shaped crystals. Twinning, both simple and polysynthetic, is common and the composition of four specimens twinned on (010), lay between 30 and 40 per cent. anorthite. Owing to the extremely slender form of most of the skeleton crystals, determination of the optical symmetry elements was difficult, and the absence of a second identifiable morphological direction also detracts from the reliability of the determinations, but in three instances in which one or both optic axes were orientable the magnitude of the optic angle (-88° , 90° & $+88^\circ$ respectively) is in agreement with the range of composition deduced from Fedoroff determinations. In three instances also, in which the maximum extinction was determinable, this also agreed with the Fedoroff determinations.

The interstices between the skeleton crystals of feldspar are occupied by grains of epidote and very minute feldspar crystallites, locally in branching arborescent growths.

The ratio between epidote and feldspar varies very considerably in different portions of the slides. In some positions there are areas occupying the whole field (2.3 mm. in diameter) in which the proportion of epidote approximates to 60 per cent., in others it falls below 10 per cent., and it is in such portions that arborescent textures are most typically developed. Locally, small aggregates of chlorite, sometimes with radial structure and polarising in the abnormal blue tint of penninite, occur in the interstices between the skeleton crystals of feldspar, but form in the aggregate a very small proportion of the rock.

Calcite occurs in small elongated lenses and irregular veinlets, and rarely as pseudomorphs after skeletal forms of feldspar.

MICRO-SLIDES 24175—6.

Albite-garnet-gneiss.

A fine-grained porphyroblastic rock in which lenticles of granular quartz and white mica sweep round porphyroblasts of albite and a few crystals of garnet.

The porphyroblasts of *albite* average slightly less than one millimetre in diameter, and, containing numerous small irregular grains of quartz, are themselves characterised by poikiloblastic texture. All the refractive indices of the feldspars are less than the lower refractive index of quartz and their anorthite content is, therefore, less than 15 per cent. They form approximately ten per cent. of the rock, and are surrounded by lenticular aggregates of small elongated quartz grains with approximately ten per cent. by volume of colourless mica, which sweep round the albite crystals and give the rock a very characteristic foliated texture. The average length of the quartz grains is approximately 0.1 mm., and of the individual flakes of mica, which are themselves segregated into very elongated lenticular aggregates, slightly more than 0.1 mm. The lenticular aggregates of quartz contain a few small grains of a dark brown, slightly pleochroic mineral of high refractive index but too small for complete optical determination.

The slides contain several large crystals of very pale brown *garnet*, round which the quartz-mica lenticles also sweep in much the same manner as round the albite porphyroblasts. They are of sub-idiomorphic contour, and their average size is approximately four square millimetres. They have undergone partial chloritisation, and, like the feldspars, contain numerous poikiloblastic inclusions of quartz.

A few small aggregates of carbonate, associated with slender prisms of chlorite are also present.

CHAPTER IV.

THE INTRUSIVE AND EXTRUSIVE ROCKS OF THE SALINGYI UPLANDS AND OF LINZAGYET.

The geology of this area, one inch to one mile sheet 84·0/1, is shown on the reduced scale of one inch to two miles in Plate 25. The portions of this sheet lying to the east of the Chindwin river and a narrow belt to the west of the Chindwin are occupied by alluvium. West of the alluvial belt, Pegu sediments are poorly exposed where the surface deposits of 'Plateau Red Earth' and 'Plateau Gravel', which are extensively developed in this area, have been removed by recent erosion. In the eastern portions of the Pegu outcrop the sediments exposed in stream sections consist of grey to buff clays and sandy shales with intercalated thin-bedded sandstones, characterised by rapid lateral variation. In a westerly direction they become progressively more arenaceous and, west of the villages of Kaingle ($21^{\circ} 47' : 95^{\circ} 3'$) and Yemein ($21^{\circ} 54' : 95^{\circ} 1'$), pass without perceptible unconformity and without the development of a recognisable 'Red Bed', into incoherent false-bedded sandstones and coarse grits of the Irrawaddy series.

One mile west of the village of Linzagyet ($21^{\circ} 51' : 95^{\circ} 5'$) is a small outcrop of basalt which was mapped by my colleague Mr. V. P. Sondhi. It is a fine-grained, black rock in which small glistening crystals of olivine are recognisable in the hand specimen. The petrological description of this rock is given on pages 160-161 (micro-slide 24177). This mass of basalt is described by Messrs. Pinfold, Day, Stamp and Chhibber¹ as—

The basalt intrusion of Linzagyet.

'A small mass of lava, a hundred feet or so in diameter, which appears to have been intruded into sands of Pegu age, chialtolite being developed near the contact. The country Pegu rocks dip towards this intrusion at steep angles.'

Three miles north of this outcrop, the Salingyi uplands rise in low, rolling undulations and reach a maximum elevation of 629 feet, two and a half miles further north. They are composed of a varied suite of intrusive and extrusive rocks with a total area of

The igneous rocks of the Salingyi uplands.

¹ E. S. Pinfold, A. E. Day, L. D. Stamp and H. L. Chhibber, *loc. cit.*, p. 170.

approximately fifteen square miles. The south-eastern margin of this outcrop consists of coarse-grained olivine-gabbro of dark-grey colour (micro-slides 24178—80) which, towards

The gabbros.

the centre of the outcrop, gives place to a gabbro of even coarser grain. The latter rock is somewhat lighter in colour and has a distinct greenish tint on the freshly fractured surface where crystals of amphibole up to five millimetres in length are recognisable (micro-slides 24181—4). Both types of gabbro contain irregular lenticular inclusions of light-

The inclusions of quartz-oligoclase-bearing rocks.

grey holocrystalline rocks consisting of quartz and felspar and numerous dark aggregates, unidentifiable in the hand specimen but which on microscopic examination proved to consist of hornblende, chlorite and epidote (micro-slides 24185—93). In some instances, the contacts between these rocks and the gabbros are ill-defined but in others they are quite sharp, and in such cases the gabbro shows evidence of intense shattering (micro-slide 24194). In most cases the quartz-bearing inclusions are less than a yard in width, and, doubtless partially due to the fact that they are well-exposed only in stream sections and small runnels, none was traced for more than a few yards in a longitudinal direction. In one case only was a large mass of this rock observed, namely in a stream section two miles south-west of the village of Saga ($21^{\circ} 57' : 95^{\circ} 8'$) where an irregular mass (seen in the right hand portion of figure 1 of Plate 29) is surrounded by shattered gabbro (seen in the left hand portion of the photograph). In order to obtain this photograph it was necessary to cut the scrub jungle which is here luxuriant, and it was not possible to expose the entire outcrop of quartz-bearing rock. The portion exposed, however, is approximately forty feet in diameter and its total cross-section may be much greater, but it was found impossible to trace the outcrop of this rock on the unbroken ground lying to the north and south of the stream.

One and a quarter miles south-west of the village of Paungwa ($21^{\circ} 58' : 95^{\circ} 8'$) the gabbros are traversed by a coarse pegmatite

The pegmatite vein.

which can be traced in a W. N. W. direction for nearly half-a-mile and which varies in width from one to four feet. It consists of a beautiful graphic intergrowth of orthoclase and quartz containing large flakes of dark green mica.

North of this point, due partially to the 'Plateau Gravel' which is widely distributed, alike over the lower slopes of the Salingyi uplands and the surrounding Pegu sediments, the igneous rocks are poorly exposed, and where good exposures again occur in the stream sections still further north, they consist of fine-grained compact rocks which I have described as hornblende-granulites (micro-slides 24195—8). These rocks, which are locally much shattered, extend to the northern margin of the Salingyi uplands where they give place to false-bedded sands of the Pegu series. At one place only, at their north-eastern extremity, is the contact with the sediments

The
granulite.

hornblende-

The hornfels.

well-exposed, and here it is characterised by induration and metamorphism of the sediments producing a very typical hornfels. It is a compact rock with sub-rectangular jointing and oblique lamination which intersects two systems of jointing and is normal to the third. Alternate laminae are grey and fawn in colour and on the weathered surface minute grains of hematite are abundant along the planes of lamination. On a freshly-cut surface, the darker laminae are of slaty hue and those which appear fawn on the weathered surface are light grey. There is considerable variation in the thickness of the laminae but on a freshly-cut surface, 3.5 centimetres thick, fifteen laminae were counted, giving an average thickness of approximately two millimetres. The petrological description of this rock (micro-slides 24199—201) appears on pages 173-174.

At their western margin, the gabbroic rocks of the southern and eastern portions of the Salingyi uplands are flanked by extrusive rocks occupying the lower western slopes and

The keratophyres.

extending as far west as the road running north and south between the villages of Pyawbwe ($21^{\circ} 57' : 95^{\circ} 4'$) and Linzagyet ($21^{\circ} 51' : 95^{\circ} 5'$). They consist of fine-grained compact featureless rocks of pale grey colour which are locally porphyritic and contain albite phenocrysts up to three millimetres in length and smaller and less numerous phenocrysts of quartz. These two types are described as keratophyre and quartz-keratophyre respectively (micro-slides 24202—5). Towards the contact with the gabbro, they become greyish-green in colour due to epidotisation, and microscopic examination reveals also striking structural alterations (micro-slides 24206—8). At the extreme north, the contact with the gabbros is characterised by the presence

of a very compact, fine-grained, pale-green rock with a splintery fracture, in which the mineral components are unidentifiable in the hand specimen but which under the microscope (micro-slide 24209) is seen to consist almost entirely of epidote and quartz. This rock occurs near the contact between both the gabbros and the keratophyres on the west, and that between the gabbros and the Pegu sediments to the north, and, owing to the absence of good exposures, it was impossible to determine to which contact it should be assigned.

The relationships to one another of the various rocks described above, and to the surrounding Pegu sediments, is obscured by the presence of 'Plateau Gravel' and 'Plateau Red Earth' which overlie both the lower portions of the igneous outcrop and the surrounding sediments. It is inevitable, therefore, that hypotheses as to their mutual relationships should rest principally on petrological grounds, and they are, therefore, deferred for later consideration. It may be stated, however, that the occurrence of hornfels at the north-eastern margin of the hornblende-granulite outcrop appears to indicate that this rock is intrusive into the Pegu sediments. In a later section, the hornblende-granulite will be compared with the beerbachites of the Odenwald and other localities, which have been variously described as dykes, metamorphosed sediments and metamorphosed igneous rocks. The form of the hornblende-granulite outcrop precludes the hypothesis that it is a dyke, but it may eventually be regarded as an intrusive rock. If, on the other hand, it is regarded as a sediment, metamorphosed by the gabbro, the hornfels should be regarded as the product of a lower grade of metamorphism of the Pegu sediments, consequent on the intrusion of the gabbro.

Messrs. Pinfold, Day, Stamp and Chhibber¹ regarded the rocks of the Salingyi complex as intrusive and in their very brief remarks on the subject state:—

'South of Salingyi there occur large masses of holocrystalline rocks such as diorite with basic developments such as amphibolite, intruded, apparently, into sands of Pegu age.'

In the field, I also described these rocks as diorites and amphibolites, but petrological examination of my collections, apparently

¹ E. S. Pinfold, A. E. Day, L. D. Stamp and H. L. Chhibber, *loc. cit.*, p. 170.

much more comprehensive than those available to the above-mentioned authors, has convinced me that these terms are inappropriate.

Petrological Description of the Igneous and Associated Rocks of the Linzagyut and Salingyi area.

MICRO-SLIDE 24177.

Basalt (Linzagyut).

A holocrystalline rock consisting of phenocrysts of olivine and diopside, together forming approximately thirty per cent. of the rock, in a microlitic groundmass, locally with well-developed flow structure round the phenocrysts, and containing in addition to the felspar microlites, minute grains of olivine pyroxene and magnetite. Phenocrysts of olivine and pyroxene occur in approximately equal numbers but the average length of the olivine crystals being about 0.8 mm. as compared with 0.6 mm. in the case of the pyroxene, the preponderance of olivine is in the approximate ratio of four to three. The average length of the microlites, which are of bytownite composition, is 0.15 mm.

Olivine occurs in sub-idiomorphic and allotriomorphic crystals with advanced alteration to serpentine, both round the margins and along the cracks. The optic axial angle of five specimens, determined with the help of the Fedoroff stage, was 90° in three instances and -88° in the remaining two. The maximum birefringence is 0.035. Small inclusions of magnetite are frequent both in the unaltered olivine and in association with serpentine.

Sub-idiomorphic crystals of pale greenish-grey *diopside* are abundant. Cleavage is poorly developed, but simple and polysynthetic twinning on (100) is frequent. The optic axial angles of two specimens determined by the Fedoroff method were 58° and 61° respectively, and the extinction ($ny \wedge C$) of four specimens determined by the same method 40° , 41° , 42° and 43° respectively and the maximum birefringence 0.025. According to Winchell¹, these properties indicate a composition of 70 per cent. diopside in the diopside-hedenbergite series.

The groundmass contains, in addition to the felspar microlites, minute interstitial grains of olivine and pyroxene, too small for

¹ N. H. and A. N. Winchell, *loc. cit.*, p. 184.

determination, and small grains and crystals of magnetite, less than 0.05 mm. in diameter. The anorthite content of five of the micro-lites determined was between 70 and 80 per cent. Four of the specimens were twinned according to the albite law and the remaining specimen was determined by the help of well-developed cleavage on (001).

MICRO-SLIDES 24178-80.

Olivine gabbro.

A phanocrystalline rock consisting of approximately 75 per cent. feldspar (anorthite) and 25 per cent. of mafic minerals. The ferromagnesian minerals which are locally segregated into large irregular aggregates, consist of olivine, rhombic and monoclinic pyroxene and amphibole, with a little serpentine, chlorite and ore. There is considerable variation in the size of grain but the average approximates to two millimetres. The rock is remarkable for showing a reaction series of ferromagnesian minerals from olivine, through hypersthene and diopside to hornblende.

The *feldspars*, which are of stumpy habit, average two millimetres in length, but one large crystal, containing inclusions of smaller feldspar crystals, is three millimetres in length. Most of the crystals are slightly turbid, and several distinctly cloudy, due to the inclusion of minute grains of opaque dust and small grains and needles of a pale green mineral, too small for determination. Of nine specimens determined, three were pure anorthite, and the anorthite content of the remaining six varied from 85 to 95 per cent. All of the specimens measured showed polysynthetic twinning on (010), usually in combination with pericline twinning, and included five examples of albite and pericline twinning, one of albite and complex albite-carlsbad, and one of complex albite-carlsbad twinning. The remaining specimen measured consisted of two individuals twinned according to the albite law with simple baveno (right) and polysynthetic pericline twinning in one individual and polysynthetic pericline twinning in the other individual. Seven of the nine specimens showed well-developed cleavage on (001) and two also showed cleavage on (010).

Olivine forms approximately ten per cent. of the rock and occurs in subrectangular and irregular crystals with an average length of one millimetre, but with some crystals twice that length. It presents

several interesting features and for that reason has been investigated in some detail by the Fedoroff method. The optic angle of six specimens, from three different slides ranges from -84° to -86° , which, with a maximum birefringence of 0.037—0.04, indicates according to Winchell,¹ chrysolite with a molecular percentage of from 25 to 30 per cent. Fe_2SiO_4 . Many crystals show numerous inclusions of vermicular aggregates of either hematite or ilmenite arranged both in parallel planes and in some instances along irregular cracks. Most of the specimens of olivine examined in three sections of this rock show partial alteration to hypersthene, almost invariably marginal, but in some instances as much as half the original olivine crystal, particularly in the case of the smaller crystals, has been replaced by this mineral. Another type of alteration is to a fibrous mineral pleochroic from orange (parallel to the fibres) to green (normal to the fibres) and having a refractive index intermediate between canada balsam and feldspar (anorthite). The mineral has negative elongation and moderate birefringence. These properties suggest amesite or some other optically positive and strongly birefringent mineral of the chlorite group. This mineral occurs not only as pseudomorphs but also replacing olivine marginally and along irregular cracks. It is usually associated with a black opaque ore, and in one instance where there is a marginal replacement of olivine, vermicular aggregates of hematite or ilmenite, such as characterise the fresh olivine, are enclosed by it. Other specimens of olivine show alteration to serpentine, both marginal and along the cracks, associated in rare instances with minute flecks of iddingsite.

Hypersthene in irregular grains of average length of 0.5 mm. is usually associated with olivine. It is strongly pleochroic from greyish green ($\eta\gamma$) to pale pink ($\eta\alpha$) and has a birefringence of 0.013 to 0.015. The optic angle of four specimens measured by the Fedoroff method varied from -70° to -74° . According to Winchell² these properties indicate a composition of from 30 to 35 per cent. FeSiO_3 . This mineral, itself a reaction product of olivine, has undergone partial alteration to diopside and in some cases to fibrous amphibole.

Diopside is segregated into large irregular aggregates, one of which is five millimetres in length and a little over one millimetre in width consisting of many small crystals averaging 0.4 mm. in

¹ N. H. and A. N. Winchell, *op. cit.*, p. 168.

² N. H. and A. N. Winchell, *op. cit.*, p. 177.

length. The optic angle of three specimens determined by the Fedoroff method, one of which is twinned on (100), was 58° in two instances and 60° in the other, and the extinction ($n\gamma \wedge C$) 41° and 40° respectively. According to Winchell,¹ these data indicate a composition of 80 per cent. diopside in the diopside-hedenbergite series. Occasionally this mineral contains small inclusions of hypersthene, too minute for complete determination but recognisable by their pleochroism. It has locally undergone partial alteration to fibrous hornblende and in several instances also, irregular grains of diopside are entirely surrounded by well-developed hornblende showing prismatic cleavage.

Hornblende occurs in irregular crystals of average length of slightly less than one millimetre. Two types are distinguishable, one pleochroic from pale yellowish-brown ($n\alpha$) to greenish-brown ($n\beta$) and olive green ($n\gamma$) and the other from pale brown ($n\alpha$) to pale green ($n\beta$) and pale bluish-green ($n\gamma$). The optic axial angle of both was found by the Fedoroff method to be -84° but the extinction ($n\gamma \wedge C$) of the bluish-green variety, which was twinned on (100), was 14° as compared with 18° in the case of the brown-green variety. Both varieties are demonstrably associated with diopside, irregular grains of which are enclosed by them, and in some instances the two varieties appear to merge into one another, in which case a perceptible difference in the extinction is noticeable on the ordinary microscope stage. A fibrous variety of the bluish-green type is sometimes associated with hypersthene, and in one instance an irregular mosaic of hypersthene, diopside, and the pale bluish-green fibrous hornblende, entirely surrounds an irregular grain of olivine.

Small grains of *ore*, varying in diameter from 0.5 to 0.1 mm. are numerous. Many are of brassy appearance but those associated with olivine and serpentine are black.

In slide 24178, two irregular grains, 0.04 mm. in diameter, of a bright green isotropic mineral of high refractive index, probably *spinel*, occur as inclusions in a partially decomposed crystal of olivine.

MICRO-SLIDES 24181—4.

Gabbro.

A holocrystalline rock of hypidiomorphic-granular texture, consisting of approximately sixty per cent. felspar (bytownite) and

¹ N. H. and A. N. Winchell, *op. cit.*, p. 187.

forty per cent. of ferromagnesian minerals with a little ore. The ferromagnesian minerals consist of pyroxene in all stages of uralitisation to a fibrous blue-green amphibole, and in some instances to a compact brown hornblende, and a well-developed green hornblende. Grains of pyroxene and their marginal alteration products attain a diameter of two millimetres and there are a few aggregates of fibrous uralite of similar dimensions, and many smaller ones. The crystals of well-developed green hornblende average approximately one millimetre in length, and the feldspars approximately 0.75 mm. The segregation of the ferromagnesian constituents gives the rock a heterogeneous appearance.

The *feldspars* are quite fresh but the majority are intensely clouded, apparently by the inclusion of ultra-microscopic grains of opaque minerals, which however, are irresolvable and appear as a brownish turbidity even under the high power (No. 7) objective. The feldspars also contain inclusions of minute slender needles of a pale green mineral of high refractive index. Of 14 specimens determined, six have a composition of 90 per cent. anorthite, five of 85 per cent. anorthite, two of 75 per cent. anorthite, and one of 70 per cent. anorthite. They include three examples of albite and pericline twinning, two of albite, carlsbad and pericline twinning, two of albite and manebach twinning, two of carlsbad and pericline twinning, one of albite, manebach and baveno twinning, three of manebach and baveno twinning, and one of carlsbad twinning. Nine specimens showed well-developed cleavage on (001), six on (010) and one on (110).

Diopside occurs in all stages of alteration to secondary hornblende. Frequently the centre of the crystal remains unaltered and is surrounded by a fibrous aggregate of uralite, but there are also examples in which central portions of the crystal have changed to brown hornblende surrounded by little-altered pyroxene. Other crystals have partially altered to an imperfectly individualised aggregate of carbonates, possibly with an admixture of talc. Fresh specimens are colourless and determinations by the Fedoroff method indicate an optical angle of $+60^\circ$ and extinctions varying in different specimens from 41° to 45° . The maximum birefringence is 0.025. According to Winchell,¹ these properties indicate a composition of 75 per cent. diopside in the diopside-hedenbergite series.

¹ N. H. and A. N. Winchell 'Elements of Optical Mineralogy', Part 2, New York (1927), p. 184.

The *amphibole group* is represented by fibrous uralite pleochroic from pale greenish-yellow to bluish-green, but too fibrous for complete determination; a more compact secondary hornblende frequently seen surrounding particles of unaltered or little-altered pyroxene, and a well-developed compact hornblende which is not demonstrably related to pyroxene. The more compact secondary hornblende presents interesting features. Predominantly of a light green colour, it contains patches of brown hornblende of the same orientation and simultaneous extinction ($n\gamma \wedge C$, 17°), but with slightly lower maximum birefringence, that of the green variety being 0.022 and of the brown variety 0.019. This association was investigated by the Fedoroff method and is discussed in Chapter IX.

The compact hornblende, which is not demonstrably related to pyroxene, is pleochroic from pale yellowish-brown ($n\alpha$) to brownish-green ($n\beta$) and green ($n\gamma$). The optic angle as determined by the Fedoroff method, was -84° , and the extinction ($n\gamma \wedge C$) 14° . On account of the strong absorption it was impracticable to determine the birefringence, which appears, however, to be comparable with that of secondary green hornblende described above.

The fibrous variety of uralite has locally undergone partial alteration to *chlorite* which, however, is too imperfectly developed for optical determination.

Small grains of a *black opaque mineral*, are frequently associated with the secondary amphiboles. They range from fine dust to 0.7 mm. in diameter, with an average diameter, of the measurable grains, of approximately 0.1 mm.

MICRO-SLIDES 24185—7.

Quartz-oligoclase-rocks.

A holocrystalline rock consisting of approximately equal proportions of quartz and felspar (oligoclase) a little hornblende, a few aggregates of epidote and chlorite, and numerous small grains of an opaque mineral. The great variation in the size of the quartz grains makes it difficult to estimate the average grain of the rock, but neglecting the very small quartz grains, the average of the other constituents is estimated to be a little less than one millimetre.

The *felspars*, which vary in length from 0.2 to 2.5 mm., include a few crystals of idiomorphic outline but are mostly of irregular

contour, due to invasion by quartz, which in some instances occurs as a vermicular or myrmekitic intergrowth. A number of crystals are slightly bent and show strain polarisation. All are distinctly cloudy, due to the inclusion of minute particles of dust, irresolvable even under objective 7. Inclusions of small needles of hornblende [pleochroic from bright green ($n\gamma$) to pale yellowish-brown ($n\alpha$)] and small grains of an opaque mineral are also numerous. Six specimens determined showed a range of composition of from 25 to 35 per cent. anorthite, and of twenty specimens determined by the Becke method, sixteen fell within the range (22 to 33 per cent. An.) while the remaining four were between 15 and 22 per cent. anorthite. The six specimens determined by the Fedoroff method include two examples of simple albite twinning, with a manebach lamella in one of the individuals in each case; one example of simple albite twinning; one of simple carlsbad twinning, with polysynthetic twinning in one individual, and one of complex albite-carlsbad twinning, with pericline lamellae in both individuals. Four of the specimens show well-developed cleavage on (001).

Irregular and polygonal grains of *quartz*, varying from 0.05 to 1 mm. in diameter, surround and penetrate the felspar crystals. The larger aggregates of quartz are characterised by incipient hornfels structure, and many of the larger grains show pronounced strain polarisation, while a few contain minute inclusions of an opaque mineral.

Hornblende occurs in a few irregular aggregates, the largest of which is one millimetre in length. It shows well-developed prismatic cleavage, and is pleochroic from pale brown ($n\alpha$), to olive-green ($n\beta$) and deep bluish-green ($n\gamma$), but is too fragmentary for complete optical determination.

Small acicular aggregates of *chlorite*, frequently with nodes of an opaque mineral, are numerous.

Epidote occurs in small aggregates of irregular form, the largest of which is two millimetres in diameter. It is usually accompanied by leucoxene and associated with small fragments of amphibole or grains of an opaque mineral, or both.

Irregular grains of an *opaque mineral*, black by reflected light, are abundant. The largest is 0.2 mm. in diameter, but the average size is much smaller.

The texture of this rock is illustrated by figure 2 of Plate 33.

MICRO-SLIDE 24188.

Quartz-bytownite-rock.

This rock is remarkably similar in texture and in mineralogical composition to the three slides last described, except that the feldspars are more basic. The composition of five specimens determined, lay between 75 and 95 per cent. anorthite, and investigation by the Becke method indicated that the anorthite content of all the feldspars was more than fifty, and, therefore (*vide* page 275) not further determinable by this method.

MICRO-SLIDES 24189—92.

Quartz-oligoclase-rocks.

A holocrystalline rock consisting of approximately equal proportions of quartz and feldspar (oligoclase and andesine), with a little hornblende and biotite and a few grains of ore and zircon. Neglecting minute grains of granulated quartz, the average grain size is approximately one millimetre.

Quartz occurs in large irregular grains, up to two millimetres in diameter, and in aggregates of small grains surrounding the larger grains and occupying the interstices between the feldspar crystals. Many of the larger crystals show pronounced strain. In several instances stringers of small quartz grains penetrate and traverse crystals of feldspar. Many, but not all of the grains in individual aggregates have a similar optical orientation, as is evidenced by the introduction of an optical sensitive plate. The emergence of ($n\gamma$) in individual grains composing eleven distinct aggregates in micro-slide 24190 was measured by means of the Fedoroff stage. The results of these measurements are plotted in the stereograms comprising text figures 3-6 (pages 210-213), in which the segregation of poles illustrates the similarity in the optical orientation of the grains composing the aggregates. Many of both the large and small grains of quartz contain minute inclusions of opaque dust.

The *feldspars* are all of higher refractive index than canada balsam and are clouded by inclusions of minute grains of dust. Many crystals show a marginal replacement or intergrowth with small grains of granulated quartz which in some cases also traverse the feldspar in the form of stringers. Small inclusions of a mineral of

higher refractive index and pleochroic from greenish-brown to deep bluish-green are common. The anorthite content of six specimens determined lay between twenty and twenty-five per cent., and of 31 specimens determined by the Becke method, the anorthite content of 21 lay between 15 and 22 per cent. and of 10 between 22 and 33 per cent. Of the six specimens determined by the Fedoroff method, five showed combined albite and pericline twinning, while the remaining specimen showed only pericline twinning. Five of the six specimens showed well-developed cleavage on (001).

Hornblende occurs in frayed crystals without idiomorphic form and rarely with good cleavage. It is strongly pleochroic from pale brownish-green to very dark blue (approaching black) ($n\alpha$ pale brownish-green, $n\beta$ very dark blue, $n\gamma$ very deep greenish-blue). It is optically negative and shows very strong dispersion, $\rho > \nu$. The maximum extinction is 21° and the optical axial plane coincides with the crystallographic symmetry plane. The optic angle, as determined by the help of the Fedoroff stage, is 17° . Owing to the strong absorption and dispersion it was impracticable to measure the birefringence.

This mineral contains inclusions of small grains of ore and flecks of biotite, and is occasionally intergrown with biotite in such a manner as to suggest that the latter is an alteration product.

The *biotite*, which is almost invariably associated with amphibole, shows good cleavage and is very strongly pleochroic from orange-brown ($n\alpha$) to nigger-brown ($n\gamma$).

Zircon occurs as a few small grains of irregular contour, the largest being 0.1 mm. in diameter.

Small grains of *ore*, black by reflected light, occur as inclusions both in the feldspars and in the amphibole.

MICRO-SLIDE 24193.

Quartz-oligoclase-rock.

A holocrystalline rock composed of approximately 45 per cent. feldspar (oligoclase), 35 per cent. quartz and 20 per cent. epidote, with a few small grains of pyroxene, wisps of hornblende and grains of ore. The average grain size is 0.7 mm. but a few of the feldspars attain a length of two millimetres.

Feldspar occurs in irregular and frayed rectangular crystals the average length of which is one millimetre. They frequently show

advanced marginal granulation sometimes with minute quartz grains interspersed among the grains of granulated felspar. Some of the crystals are slightly bent and show strain polarisation. Inclusions of minute grains of opaque dust and minute needles of a pale green mineral, with oblique extinction, positive elongation and refractive index higher than the host, occur in the ungranulated portions of the felspars. Inclusions of small grains of epidote are also common. The composition of four specimens determined, lay between 25 and 30 per cent. anorthite. They included three examples of albite in combination with pericline twinning and one of albite-carlsbad and pericline twinning. Two of the specimens showed well-developed cleavage on (001). Of fourteen specimens determined by the Becke method, twelve lay within the same range of composition (22 to 33 per cent. anorthite) and two between 15 and 22 per cent. anorthite.

Quartz is segregated into irregular aggregates varying from one to four millimetres in diameter and composed of many allotriomorphic grains of different optical orientation and average diameter of 0.5 mm. Smaller grains of quartz, approximating to 0.05 mm. in diameter, are associated with felspar in the granulated margins of this mineral. Neither the large nor the small quartz grains show appreciable strain but both contain inclusions of opaque dust and minute needles of a colourless mineral of high refractive index, transverse sections of which have a subhexagonal contour. The needles are too small to permit the determination of either their extinction or the sign of elongation, since their thickness is too small to influence either the interference tint or the extinction of the host, but from their form and high refringence it is concluded that they are probably apatite.

Epidote crystals up to 0.8 mm. in length, are segregated into radial aggregates varying from 1 to 2.5 mm. in diameter. It is strongly pleochroic from colourless ($n\alpha$) to pale greenish-yellow ($n\beta$) and bright yellow ($n\gamma$). The maximum birefringence is 0.36, the optic angle (estimated) -70° and the extinction $n\gamma \wedge$ cleavage (001) 29° . Associated with this mineral are abundant grains of *leucoxene* and in two instances several small crystals of *sphene*, the largest of which is 0.3 mm. in length. Epidote occurs also in small grains, as inclusions, in both felspar and quartz.

Hornblende occurs in small needles, the average length of which is 0.2 mm. These are too small for complete optical determination

but the extinction is 21° from the long axis of the needles, the elongation is positive and the pleochroism bluish-green (parallel to needles) to pale olive-green (normal to the needles). A similar mineral occurs as inclusions in the feldspars, but forms in the aggregate less than one per cent. of the rock.

A few small irregular grains of *pyroxene* are present. Averaging only 0.2 mm. in diameter, they are too small for determination but the mineral is recognisable by its high refringence and birefringence and the absence of pleochroism, which is pronounced in the case of epidote.

Small irregular grains of a *black opaque mineral*, of average diameter of approximately 0.1 mm. are rare and almost entirely restricted to the aggregates of epidote.

MICRO-SLIDE 24194.

Shattered gabbro.

A holocrystalline rock consisting of approximately 85 per cent. feldspar (bytownite), ten per cent. of pyroxene, grains and veins of epidote associated with leucoxene and ilmenite, and in one instance a little quartz and zoisite. Some of the feldspars show advanced granulation but, neglecting the minute feldspar granules, the average grain size is approximately one millimetre.

The most remarkable feature of the rock is the intense granulation of the *feldspars*. In some instances the granulation is complete, resulting in an aggregate of minute granules approximately 0.01 mm. in diameter; in others the granulation is marginal and in such cases the remaining portions of the original crystals are either bent or broken and show pronounced strain polarisation. In broken crystals, granulated zones sometimes occur along the fractures and in other cases the cracks are filled by veinlets of epidote. The ungranulated crystals of feldspar contain dispersed inclusions of minute grains of opaque dust, which however, are by no means as numerous as in the feldspars of some of the other specimens of gabbro. The composition of three specimens of feldspar determined, was in two cases 85 per cent. anorthite and in the other 90 per cent. anorthite. They are characterised by polysynthetic albite and pericline twinning, in one instance in combination with albite-albite twinning.

In the pyroxene crystals, averaging 0.5 mm. in length, the effects of the crushing, which has resulted in the granulation of the felspars are not recognisable. The mineral which is very pale greyish-green in colour, has an optic angle of $+60^\circ$ (estimated), an extinction ($n\gamma \wedge C$) of 44° and a maximum birefringence of 0.023. It shows local replacement by epidote, but in contrast to the other specimens of gabbro, shows no trace of uralitisation.

Irregular veins of *epidote* traverse the rock and irregular aggregates of the same mineral appear to replace pyroxene. It is strongly pleochroic from very pale yellow to bright yellow but the individual grains are too small for complete optical determination. In a number of grains a core of *allanite* (pleochroic from greenish-yellow to deep brown) is surrounded by a margin of the normal yellow epidote. This mineral is frequently associated with leucoxene and ilmenite and, in the largest vein which traverses the slide, and which attains a width of one millimetre, with a few grains of quartz, varying in diameter from 0.05 to 0.1 mm. and showing no sign of the strain which is so pronounced in the felspars of this rock. In this vein a few small needles of *zoisite* also occur.

Leucoxene occurs in a number of subhexagonal and irregular pseudomorphs after *ilmenite*, frequently with an opaque core of this mineral, and also in chain-like aggregates of small grains, to which the term 'insect-egg structure' has been applied. It is also associated with epidote in the veins which traverse the rock. The large pseudomorphs having sub-idiomorphic outline average 0.5 mm. in diameter.

MICRO-SLIDES 24195—8.

Hornblende-granulite.

A holocrystalline granulitic rock composed of an equigranular mosaic of felspar (andesine) and hornblende with numerous grains of ore and a little biotite. The average grain size is 0.4 mm. but three of the four slides of this rock are traversed by more coarsely crystalline veins composed of the same minerals, with similar structural relationships, in which the average grain size approximates to one millimetre. There is a sub-parallel orientation of the crystals which gives the impression of rudimentary schistosity when viewed under low-power objectives, but under higher powers the predominating impression is that of hornfels structure. Neither

the feldspar nor the hornblende crystals have developed idiomorphic contours and their mutual interference suggests crystalloblastic growth.

The majority of the feldspars are quite fresh but many of them are slightly clouded by the inclusion of minute grains of opaque dust which is usually concentrated in the centre of the crystals. The composition of nine of the feldspars determined lay between 45 and 50 per cent. anorthite. In all but one instance, they showed negative elongation and polysynthetic twinning on (010), in three instances in combination with pericline twinning in one or more of the hemitropes. The other example, with positive elongation, was characterised by polysynthetic manebach twinning in combination with albite and complex albite-ala twinning. Six of the nine specimens show well-developed cleavage on (001).

The rock also contains another exceptional type of feldspar, which occurs in larger crystals, up to one millimetre in diameter, occurring occasionally in both the fine- and coarse-grained portions of the rock with, in one slide, a predilection for the coarser-grained veins. It is characterised by a basic core, which has undergone partial sericitisation, surrounded by a narrow margin of clear feldspar of much more acid composition. These large feldspars are well seen in the microphoto given as figure 1 of Plate 34. In six examples determined, the anorthite content of the partially decomposed central portion, lay between 80 and 90 per cent. and that of the clear margin between 45 and 50 per cent. The boundary between the clouded basic, and the clear acid portions, although irregular, is sub-parallel to the final contours of the crystal if the scalloped edges, produced by the intergrowth with hornblende, are disregarded. I have studied many examples of zoning in feldspars but this phenomenon is quite different, and is considered to be due to albitisation, by which is understood a marginal replacement of the basic feldspar by a secondary growth of feldspar of intermediate composition. The turbidity, due to sericitisation, of the central basic portions of these feldspars is also quite distinct from the diffused turbidity of the feldspars shown by several of the gabbros, and which is caused by the inclusion of innumerable minute grains of opaque dust.

The *hornblende* consists of compact allotriomorphic crystals, frequently with well-developed prismatic cleavage. The pleochroism is from pale yellowish-brown ($n\alpha$) to brownish-green ($n\beta$) and deep olive-green ($n\gamma$) and the extinction is 21° . Owing to the strong

absorption, the accurate determination of the birefringence was impossible. The optic angle (estimated) is approximately -70° and the dispersion $\rho > V$. Inclusions of a black opaque mineral are frequent and partial alteration to biotite is somewhat rare.

Small lath-shaped and sub-hexagonal crystals of *biotite*, sometimes partially intergrown with hornblende, and in others surrounded by grains of feldspar, occur sparingly. Their average length is 0.4 mm. and they form less than one per cent. of the rock. The mineral is strongly pleochroic from pale brown ($n\alpha$) to dark brown ($n\gamma$).

Small grains of a black *opaque mineral*, varying from 0.2 to 0.5 mm. in diameter, are abundant and are almost invariably associated with hornblende.

Many of the feldspars contain inclusions of small needles of a colourless mineral of high refractive index, but being of insufficient thickness to affect the interference colour or the extinction of the host, it was impracticable to determine their extinction or the sign of their elongation. From their form and refringence, they are thought to be apatite.

Slide 24197 contains a few small aggregates of a colourless amphibole, of which the optic angle, determined by the Fedoroff method, varies from -86° to $+89^\circ$, and the extinction ($n\gamma \wedge C$) is 17° . No section of maximum birefringence was found.

MICRO-SLIDES 24199—201.

Hornfels.

In thin section, the lamination seen in the hand specimen of this rock (*vide* page 158) is not recognisable, but it is probably responsible for sub-parallel cracks which traverse slide 24201, and along the margin of one of which there is a local segregation of hematite.

The mineral constituents are quartz, white mica and oligoclase, with many small grains of ore and a little biotite.

Quartz, consisting of irregular and polygonal grains, with an average diameter of 0.5 mm., forms approximately 75 per cent. of the rock, and occurs as an equigranular mosaic surrounding nests of white mica. A few grains show slight strain but the majority extinguish uniformly. Minute inclusions are common and consist of grains of opaque dust, small irregular grains of a colourless mineral with high refringence and birefringence, and small laths and hexagonal plates of biotite.

White mica occurs in irregular aggregates of minute scales, ranging from 0.3 to 0.5 mm. in diameter, and forms approximately twenty per cent. of the rock. These nests of white mica bear a strong resemblance to the degradation product of andalusite in a series andalusite-disthene rocks described by Dr. F. Spaenhauer¹ from the Silvretta nappe and it is thought that they may be pseudomorphs after this mineral or after cordierite, of which minerals, however, no trace can be found. Another possibility is that they were formed by low grade metamorphism of the argillaceous cement of the original sandstone, which was insufficient to result in the crystallisation of andalusite or cordierite.

A few feldspars occur as isolated crystals in the quartz mosaic which forms the bulk of the rock. Three specimens determined showed a range of composition of from 25 to 30 per cent. anorthite, and were all characterised by polysynthetic albite twinning and well-developed cleavage on (001).

Minute grains of hematite, averaging 0.2 mm. in diameter, are numerous and there is a segregation of this mineral along the margin of one of the cracks which traverse slide 24201.

Small laths and sub-hexagonal plates of *biotite* are frequently associated with the aggregates of white mica, and attain in some instances a length of 0.3 mm. which is much larger than the individual flakes of white mica, but they form in the aggregate but a small proportion of the micaceous minerals. As mentioned above, *biotite* is also represented among the inclusions in quartz.

MICRO-SLIDES 24202—3.

Keratophyre.

A porphyritic rock consisting of phenocrysts of albite in a micro-litic to sub-trachytic groundmass, consisting of feldspar microlites, interstitial quartz, numerous grains and aggregates of epidote, leucoxene and ore, and acicular aggregates of chlorite. The average length of the phenocrysts, which form approximately five per cent. of the rock, is 0.5 mm.

The *feldspar* phenocrysts are all of lower refractive index than canada balsam, and frequently contain small aggregates of epidote and show a greyish-brown turbidity due to the inclusions of minute

¹ F. Spaenhauer, 'Die Andalusit- und Disthen-vorkommen der Silvretta', *Min. Petr. Mitt. Schweiz*, Bd. XIII, pp. 323-343, (1933).

grains of ore. The anorthite content of nine specimens determined is between five and ten per cent. Six of the eleven specimens measured showed twinning on (001), the following laws being realised:—albite; manebach, acline, pericline, ala, albite-ala, manebach-ala, and manebach-acline. Two of the eleven specimens show well-developed cleavage on (001).

Epidote occurs in small grains and aggregates and in a veinlet in which it is associated with abundant ore and *leucoxene*. The individual grains are too small for complete determination but are recognisable by their high refringence, birefringence and pleochroism from colourless to pale brownish-yellow.

An *opaque mineral*, black by reflected light, is abundant both as minute grains and in larger grains up to 0.2 mm. in diameter.

Small acicular aggregates of *chlorite*, pleochroic from pale green ($n\alpha$) to deeper green ($n\gamma$) are numerous.

Throughout the groundmass the felspar microlites are for the most part arranged radially but around the phenocrysts rudimentary flow texture is in evidence. Glass is absent from the groundmass, the interstices between the microlites being occupied by irregular grains of quartz.

MICRO-SLIDES 24204—5.

Quartz-keratophyre.

A glomeroporphyritic rock consisting of phenocrysts of quartz and felspar (albite and oligoclase), with a few aggregates of chlorite and epidote in a micro-crystalline matrix, the proportion of matrix to phenocrysts being approximately three to one. Among the phenocrysts, felspar is almost twice as abundant as quartz. The average length of the phenocrysts is 1.5 mm.

All the *felspars* are of lower refractive index than canada balsam and a few are untwinned. They vary in size from 0.3 to 2.5 mm. and are all intensely clouded due to the inclusion of minute particles of dust and occasional grains and needles of a pale green mineral. The eleven specimens determined, range in composition from 5 to 15 per cent. anorthite. They include four examples of albite twinning; one of albite and pericline twinning; one of carlsbad; one of albite and carlsbad, one of albite, carlsbad and complex albite-carlsbad, one of carlsbad and pericline, and two of ala combined with albite twinning. Eight of the eleven specimens show well-developed cleavage on (001) and two also showed cleavage on (010).

The *quartz* phenocrysts, all of which show pronounced corrosion, vary in size from 0.4 to 2.5 mm. Many show undulose extinction and all contain numerous minute inclusions of a very pale pink mineral with a high refractive index, and a few of a pale green mineral of low relief and low birefringence, associated in some instances with a black opaque mineral of subrectangular outline.

There are a few of both irregular and acicular aggregates of *chlorite*, pleochroic from pale to slightly deeper green, the largest of which is one millimetre in diameter, and a few aggregates of *epidote*, pleochroic from colourless to pale yellow, somewhat smaller and less abundant than the *chlorite* aggregates. The *epidote* is frequently associated with *leucoxene* and small grains of a black opaque mineral, and occasionally with *chlorite*.

Grains of *ilmenite*, ranging in diameter from 0.05 to 0.3 mm. are abundant and are almost invariably associated with *leucoxene*, *epidote* or *chlorite* or with all three of these minerals.

The slides also contain a few grains of *zircon*, the largest of which is 0.1 mm. in diameter.

MICRO-SLIDES 24206—7.

Altered keratophyre.

A holocrystalline rock with a tendency to glomeroporphyritic texture and consisting of sheaves of *felspar* laths (*albite*), some 0.3 mm. in length, and a few isolated crystals of *albite* averaging 0.5 mm. in length, in a groundmass consisting of minute grains of *felspar* and *quartz* with micro-granitic structure and containing much *epidote*. The latter mineral, which occurs in aggregates attaining 0.8 mm. in diameter, and also in minute grains dispersed throughout the groundmass, forms approximately ten per cent. of the rock, while the crystals and sheaves of *albite* laths form approximately five per cent.

Felspar occurs in bundles of lath-shaped crystals frequently with a pronounced radial arrangement and in a few idiomorphic crystals averaging 0.5 mm. in length. Many of the individuals forming radial aggregates show strain polarisation which, however, is not noticeable in the larger idiomorphic crystals, which show slight marginal corrosion. The composition of both types was determined and the *anorthite* content of the laths occurring in bundles and radial aggregates was five per cent. as compared with

ten per cent. in the case of the larger isolated crystals. Minute felspar grains also occur in the groundmass where they form an equigranular mosaic with quartz but owing to the minute size of the grains (less than 0.02 mm.) and the similarity in refractive index of the two minerals, no estimate of their relative proportions is possible.

The *epidote* aggregates consist of minute grains of this mineral, too small for optical determination, but recognisable by their high refringence and birefringence. Small grains of this mineral are also dispersed throughout the groundmass where it is sometimes associated with minute grains of *leucoxene*.

MICRO-SLIDE 24208.

Altered keratophyre.

A fine-grained holocrystalline rock, consisting essentially of epidote and quartz, with a little chlorite, ore and sphene and a few acicular aggregates of hornblende.

Epidote in the form of aggregates of small grains permeates the whole rock of which it forms approximately seventy per cent. It is too imperfectly individualised for complete optical determination but many grains show the reddish and brown tints which are characteristic of allanite; others show the pleochroism in shades of yellow typical of normal epidote. *Sphene* occurs in association with this mineral in many of the aggregates and is usually accompanied by a little *leucoxene* with its characteristic milky appearance by reflected light.

The *quartz*, which occupies the interstices between the epidote aggregates, is remarkable for the large number of inclusions of minute needles of a pale green mineral and a few of a colourless mineral. Owing to their minute size it is impracticable to distinguish either their extinction, or the sign of elongation, but they have a refractive index appreciably higher than the quartz.

Small grains of a black *opaque mineral*, which when examined by reflected light is seen to be mottled by small white flecks, are abundant. They range from 0.1 to 0.3 mm. in diameter and are predominantly of irregular form but a few of the smaller grains are square in outline.

Sphene occurs in a number of small rectangular and lozenge-shaped crystals a few of which are twinned and the largest of which

is 0.25 mm. in diameter. It is invariably associated with epidote and usually accompanied by a little leucoxene.

Small acicular aggregates of bright green *hornblende* frequently occur on the margins of the epidote aggregates and are usually partially enclosed by quartz. Some of them are partially altered to *chlorite* and small needle-shaped aggregates of the latter mineral are also probably pseudomorphs after *hornblende*.

MICRO-SLIDE 24209.

Quartz-epidote rock.

Macroscopically, a dense, pale green rock in which narrow laminae of very pale green colour alternate with irregular bands of deeper green.

Microscopically, the rock is seen to consist of *quartz* and *epidote* in the approximate ratio of 6 to 4. The slide is traversed by alternating irregular lenses of quartz and epidote but in the case of one broad vein consisting predominantly of quartz, numerous grains and small aggregates of epidote are interspersed with this mineral. In this vein the individual irregular grains of quartz, averaging 0.3 mm. in diameter, are smaller than in the other lenses of this mineral. In the other quartz lenses, which also consist of mutually interfering grains of quartz of varying optical orientation, the average grain size is 0.6 mm. but in these lenses also, small nests of finer-grained quartz occur and like the large aggregate of fine-grained quartz, are accompanied by a few small grains of epidote. The majority of the quartz grains are without strain but a few show slight undulose extinction. Many of the grains show inclusions of minute needles of a mineral with strong relief.

The irregular lenses of *epidote* are characterised by fan-shaped aggregates of this mineral in which individual crystals vary from 0.4 to 1 mm. in length. The mineral is strongly pleochroic from colourless ($n\alpha$) to pale yellow ($n\beta$) and bright yellow ($n\gamma$). The optic angle (estimated) is -70° and the maximum birefringence 0.035. In one specimen twinned on (100) the extinction from the association plane ($n\alpha \wedge C$) is 3° and measured from the cleavage ($n\gamma \wedge (001)$) 28° .

In addition to quartz and epidote, the slide contains numerous grains of a brown *opaque mineral* varying in diameter from 0.1 to 0.5 mm. and almost invariably associated with epidote.

CHAPTER V.

THE EXTRUSIVE AND INTRUSIVE ROCKS OF THE INGYINTAUNG AND POWINTAUNG AREAS.

The geology of this area, one inch to one mile sheet 84. J/16, is shown on the reduced scale of one inch to two miles in Plate 25. The eastern portion of this sheet, south of the North Yama Chaung, is occupied by typical sediments of the Pegu series, consisting of alternating clays and sandy shales and false-bedded sandstones. At the extreme south the general elevation approximates to 600 feet, falling gradually in a northerly direction to 300 feet in the neighbourhood of the North Yama Chaung, but the topography is diversified by the conspicuous hog-backed hill of Powintaung, rising to over 900 feet. This hill is formed of massive soft sandstones, capped by indurated silicified sandstones, and is flanked on the west by a steep scarp falling precipitously for 400 feet from its pagoda-capped summit. The hill is noted for the numerous ancient caves which have been excavated in the lower portions of the soft sandstones, a few of which are shown in the photograph comprising figure 2 of Plate 29, which also illustrates the massive nature of the sandstones.

The general trend of the Powintaung scarp is again recognisable in Ingyintaung (Hill 550) situated three miles to the north, which is also composed of massive sandstones resting on a very distinctive conglomerate, some four feet thick and composed of rectangular and subrectangular fragments of shale in a matrix of soft, buff sandstone. Two miles north of Ingyintaung, the Pegu sediments contain large irregular lenticles of impure limestone which have given rise to a flourishing lime-burning industry near the village of Maukthayet ($22^{\circ} 7' : 94^{\circ} 58'$) and from which the Miocene fauna described on pages 129-130 was collected. West of the Pegu outcrop shown on the map (Plate 25), the low land extending as far as the main road running north and south from Yinmabin ($22^{\circ} 5' : 94^{\circ} 54'$) to Thayetkan ($22^{\circ} 0' : 94^{\circ} 54'$) (the western boundary of the area mapped by me) is occupied by a rich, black alluvial soil. The Pegu-Irrawaddian boundary is not exposed, but my own mapping to the south, and that of my colleagues to the west and north, indicate that it probably lies very near to the western margin of the Pegu outcrop.

The conglomerate underlying the sandstones of Ingyintaung is immediately underlain by andesites, the outcrop of which is four and half miles in length and varies from a quarter to one and a half miles in width. Their relationship to the Pegu sediments is illustrated by text figure 2. The andesites vary from light grey



Fig. 2.—Cross section along the line A—B (see Plate 25), commencing three miles W. S. of

W. of Maukthayet and continuing to two and a half miles W. S. W. of

Dondaw. Horizontal scale 1 inch = 1 mile. Vertical scale $\times 4$.

A = Andesite; Al = Alluvium; C = Conglomerate;

F = Miocene fossil horizon (*vide* page 129);

P = Pegu series; R = Rhyolitic tuff.

to greyish-brown in colour and contain numerous phenocrysts of felspar and aggregates of a pale green substance, unidentifiable in the hand specimen but recognised as palagonite in the thin sections (micro-slides 24210—20). The surface of the outcrop is locally vesicular and amygdaloidal, the amygdules consisting of colourless or pale blue silica, frequently with a thin crust of a green or pale greenish-brown mineral (micro-slides 24221—3). In the neighbourhood of Maukthayet ($22^{\circ} 7' : 94^{\circ} 58'$), the andesites are copiously veined with quartz and large geodes of banded agate are abundant. Towards the south of the outcrop, amygdaloidal varieties are rare and geodes of agate were not observed, but veins of calcite, some of which are water-clear and show highly developed rhombohedral cleavage, are numerous. Along its western margin, the main andesite outcrop is partially buried by the alluvium of the Nagamaung Chaung, west of which andesites are again very poorly exposed at the eastern margin of a small Pegu inlier. Here, however, their relationship to the Pegu sediments is obscured by a considerable thickness of coarse 'Plateau Gravel'.

One and a half miles north-east of the northern extremity of the andesite outcrop, a small outcrop of kaolin containing many

large plates of biotite, is exposed in the south bank of the North Yama Chaung. On the unbroken ground south of the stream, small exposures of similar material occasionally protrude through the sediments, which, owing to a cover of 'plateau gravel' are very poorly exposed. It appears, however, that the aggregates of kaolin and biotite are the weathering product of an intrusive rock of which no unweathered outcrops were discovered. These weathering products were much too friable for the preparation of thin sections, and in the absence of positive evidence, I advance the hypothesis that the parent rock was probably a mica-porphyry.

To the west of Powintaung, is a small outcrop, approximately half a square mile in area, of micro-hornblende-gabbro. It is a

The micro-hornblende-gabbro intrusion.

very compact, fine-grained rock, black in colour (micro-slides 24224—5) which towards the contact with the sediments is lighter in colour and appears somewhat schistose, and microscopic examination (micro-slide 24226) reveals the presence of epidote which is absent from specimens collected from the centre of the outcrop. The eastern contact with the sediments is also characterised by a

foliated, crumpled, schistose rock containing abundant sericite, and further east, between the contact and the western flank of Powintaung, the low ground is occupied by soft, friable rocks containing abundant kaolin. The richness of these rocks in kaolin caused me to adopt the field hypothesis that these rocks are tuffs, or at least tuffaceous sandstones, but microscopic examination affords no confirmation of this hypothesis. They consist (micro-slides 24227—8) principally of quartz, kaolinised felspar and nests of colourless mica, and, apart from their advanced state of weathering, bear a striking mineralogical and textural resemblance to the hornfels occurring at the contact of the hornblende-granulite with the Pegu sediments (*vide* page 158 *supra*). Similarly, in the field the highly foliated rock occurring at the contact with the micro-hornblende-gabbro, was thought to be a metamorphosed tuff. In this case (micro-slide 24229), metamorphism is so far advanced that recognition of the original character of the rock is impossible, but its microscopic characters suggest that it may be an older country rock brought up by the gabbroic intrusion. In this region, exposures are poor, owing both to the luxuriance of the jungle and the thickness of the soil cap, but in the field I was satisfied that this rock was *in situ*. For the same reasons, its relationship to the kaolin-bearing rocks is also obscure, but, if, as I now believe, these rocks are low grade contact metamorphosed sediments, the extent of the aureole suggests that the gabbroic intrusion has a fairly large sub-surface extension at no very great depth.

Petrological Description of the Igneous and Associated Rocks of the Ingyintaung and Powintaung areas.

MICRO-SLIDES 24210—2.

Andesite.

A porphyritic rock consisting of approximately 25 per cent. of zoned felspar phenocrysts, ranging in composition from andesine to bytownite, with a few phenocrysts of corroded biotite and numerous pseudomorphs of opal, delessite and hematite, in a pilotaxitic groundmass, containing in addition to the felspar microlites numerous grains and acicular crystals of an opaque mineral and a few amygdules of crypto-crystalline silica, the largest of which is 1 mm. in

length and 0.2 mm, in width. The felspar microlites, averaging only 0.1 mm. in length, are too small for determination.

The *felspar* phenocrysts are of stumpy habit and locally show marked segregation into stellate clusters. The largest crystal is 2.3 mm. in length but the average is approximately 1 mm. The majority are conspicuously zoned and a few show swarms of acicular crystals of an opaque mineral oriented without reference to the crystallographic directions of the host. Four specimens determined, ranged in composition from 50 to 80 per cent. anorthite, and included two examples of albite twinning, one of albite in combination with pericline twinning, and one of albite and complex albite-carlsbad twinning. Two showed well-developed cleavage on (001) and one showed beautifully well-defined zoning on $(\bar{1}\bar{1}1)$ ($1\bar{1}0$) and $(\bar{2}01)$.

Biotite occurs in a few much-corroded phenocrysts, the largest of which takes the form of a very elongated lozenge, 2 mm. in length. All the crystals of this mineral show a pronounced resorption border of an opaque mineral which is reddish-brown by reflected light, with a strongly pleochroic core ($n\alpha$ pale straw coloured, $n\gamma$ deep orange-brown).

Pseudomorphs of rectangular, polygonal and irregular shape and of average length of 0.8 mm. are abundant. They are of two kinds, one usually with regular outlines consisting of a core of very pale pink opal, sometimes showing transverse cracks, usually associated with a green fibrous mineral with positive elongation, moderate positive relief, pleochroic from yellow (normal to fibres) to bright green (parallel to fibres) and with low to moderate birefringence. This substance appears identical with that described by Sir L. L. Fermor¹ as *green palagonite* and which he regarded as delessite. These pseudomorphs are almost invariably surrounded by a pronounced border of an opaque mineral, brown by reflected light and indistinguishable from the reaction border surrounding the biotite phenocrysts. The presumption is that some at least of the polygonal pseudomorphs are after biotite, but the rectangular ones may possibly have arisen by replacement of the felspars. A second type of pseudomorph, consists of a pale green mineral consisting in some instances of radiating fibres resembling spherulites, and in others of aggregates, apparently of the same mineral,

¹ L. L. Fermor, *op. cit.*, p. 133.

showing aggregate polarisation resulting from promiscuous orientation of the fibres. In both cases the refractive index is slightly higher than canada balsam and the elongation of the fibres positive, and the birefringence possibly slightly lower than in the case of the green mineral occurring in the formerly described pseudomorphs. Another apparent distinction from this mineral is the absence of pronounced pleochroism, but it is thought that this may possibly be due to the less regular orientation of the fibres. Certainly if this is the same mineral, it is less perfectly individualised than in the case of the former pseudomorphs where it is associated with opal, and in its imperfectly determinable state the author proposes to follow Sir L. L. Fermor in terming it green palagonite. In this instance, there is no evidence either in the form or in remnants of the original mineral to enable any final conclusion to be drawn as to the mineral which is replaced by this type of pseudomorph, but it is suggested that it was some ferro-magnesian constituent of which no trace remains, except in slide 24212 in which corroded remnants of a very strongly pleochroic amphibole (α yellowish-brown, γ very deep orange-brown) with high birefringence occur.

Hematite occurs in abundant small grains and needles of average length of 0.2 mm. scattered throughout the groundmass, and in a few instances as inclusions in the felspar phenocrysts.

The slide contains a few small amygdules of cryptocrystalline silica, occasionally with perceptible rhythmic banding.

MICRO-SLIDES 24213—5.

Andesite.

A porphyritic rock consisting of approximately 30 per cent. of zoned felspar phenocrysts of labradorite-bytownite composition, and average length of 1 mm., in a pilotaxitic groundmass of minute microlites of felspar, locally with pronounced flow structure which is particularly noticeable around the few large grains of ore. The rock contains also a few pseudomorphs of carbonate, hematite and brown and green palagonite after some ferromagnesian mineral.

The *felspars* show polysynthetic twinning on (010) and pronounced zoning. Four specimens determined, range in composition from 85 per cent. anorthite to 60 per cent. at the margin. Three show well-developed cleavage on (001) and one also on (010). The majority show local replacement by a green fibrous mineral

of lower refractive index than the felspar and apparently of a similar nature to the green palagonite described in connection with the previous slides (24210—2). They also contain numerous minute grains of opaque dust. Two examples in slide 24215 show magmatic corrosion and in these cases the original twinning lamellae are still recognisable but are almost entirely replaced by groundmass. One is entirely surrounded by a border of hematite, showing aggregate polarisation, and resembling a reaction rim frequently seen surrounding biotite phenocrysts in slide 24210. This rim of hematite is seen in the micro-photo given as figure 2 of Plate 34. In another example in the same slide, a core of clear felspar is surrounded by a broad margin in which the outer zones have been replaced by groundmass, and here also there is a pronounced rim of hematite. In other examples, showing partial replacement by groundmass, irregular aggregates of hematite occur in the centre of the crystals, and there is yet another example in which a rectangular aggregate of hematite is surrounded by a very narrow border of clear felspar.

The slides contain several sub-rectangular and polygonal pseudomorphs, the largest of which is 1 mm. in diameter, consisting in some instances of aggregates of *hematite* and *carbonate*, and in others of mixtures of *brown* and *green palagonite*, with or without hematite. Others consist of hematite alone, bright red in colour and showing aggregate polarisation.

A *black opaque mineral*, occasionally with brown and brassy flecks, occurs in well-developed, diamond-shaped crystals and irregular grains, the average diameter of which is 0.2 mm.

MICRO-SLIDES 24216—7.

Andesite.

A porphyritic rock consisting of zoned phenocrysts of felspar ranging in composition from andesine to labradorite, of stumpy habit and average length of 1 mm.; numerous pseudomorphs after a ferromagnesian mineral; phenocrysts of hornblende and grains of ore, in a hyalopilitic groundmass which forms approximately sixty per cent. of the rock.

The *felspar* phenocrysts are conspicuously zoned, and five specimens determined showed a range of composition of from 45 to 60 per cent. anorthite. Three others determined by the zone method showed a similar range in composition. All the specimens deter-

mined were twinned on (010) and four of them showed well-developed cleavage on (001). One specimen showed remarkably sharply defined zoning on (010) and (201). Some are quite fresh but others are partly replaced by pale pink opal and some almost completely replaced by this mineral with a slight admixture of imperfectly individualised green palagonite.

Phenocrysts of *hornblende* are numerous, but occurring mostly in lath-shaped crystals of less than 1 mm. in length are greatly subordinate to the felspar phenocrysts. A few crystals show a weak resorption border but the majority appear quite fresh. The mineral is pleochroic from golden-brown ($n\alpha$) to nigger-brown ($n\beta$) and olive-green ($n\gamma$), and measurements by the Fedoroff method indicate an optical angle of -72° and an extinction of 9° .

The slide contains many pseudomorphs consisting of mixtures of *opal*, a very pale green fibrous mineral showing aggregate polarisation, and a little *talc*. The fibres have straight extinction and positive elongation and apart from the absence of marked pleochroism appear similar to the *green palagonite*, described in connection with a former rock (micro-slides 24210—2). The paler colour and absence of pleochroism may be due to the intimate association with opal and the imperfectly individualised form of the green mineral. One of the pseudomorphs, containing conspicuous nodes of banded opal, has a form reminiscent of a rhombic mineral which, since olivine and amphibole are a rare association, was probably a rhombic pyroxene. A peculiar feature of the opal in this example is the apparent difference, as judged by the Becke line, in the refractive index of successive bands of opal. Since however, there is very little difference in the relief of these bands it is thought that the strong Becke line must be due to a sub-microscopic layer of metallic salts, between the concentric bands of opal, which produces reflection phenomena at the contact. A conspicuous feature of all the pseudomorphs is the inclusion of numerous minute slender needles of a mineral with much higher refraction than either opal or the green palagonite. Under the low power these needles appear bright green in colour but when the condenser is inserted or when viewed under a higher power they are colourless. Owing to their minute size it is extremely difficult to determine their extinction when completely surrounded by other minerals, but where they project into cavities caused by the grinding of the slide they are found to have straight extinction. One pseudomorphic aggregate

contains a hexagonal crystal, 0.08 mm. in cross section, of a mineral with a similar high refractive index, and with the aid of an oil immersion lens an optic axis interference figure of a uniaxial negative mineral was obtained. In one or two instances in which pseudomorphic aggregates containing needles of this mineral are in contact with felspar phenocrysts, they are enclosed partly in the pseudomorph and partly in the felspar and it is then seen that the mineral has an appreciably higher refractive index than the felspar. Subsequent examination of the felspars under a high power objective revealed that similar needles and small hexagonal sections of the same mineral are abundant in the felspar phenocrysts. From its form and optic properties there can be no doubt that it is *apatite*, and since it occurs as inclusions both in the pseudomorphs after ferromagnesian minerals and in the felspar phenocrysts, individual needles being occasionally common to both, it is clearly a primary constituent and one which crystallised early in the solidification of the magma.

The groundmass consists of minute felspar microlites in abundant greyish-brown glass containing several square and numerous irregular grains of a *black opaque mineral* of average diameter of 0.1 mm. and abundant minute grains of opaque dust.

MICRO-SLIDES 24218—20.

Andesite.

A porphyritic rock consisting of much-altered felspar phenocrysts, with the composition of labradorite, in a hyalopilitic groundmass containing minute felspar microlites locally with pronounced flow structure, abundant grains of ore and a little glass. The average length of the felspar phenocrysts is 1 mm. but the slide contains several twice that length, and, combined with pseudomorphs after felspar, or some other phenocryst, comprise approximately twenty per cent. of the rock. The microlites averaging approximately 0.05 mm. in length are too small for determination.

The *felspar* phenocrysts show advanced alteration, some being almost entirely replaced by a fibrous aggregate of *brown palagonite* almost invariably associated with *hematite*, sometimes arranged zonally towards the margin of the phenocrysts and surrounded by comparatively clear felspar. In other examples, a core of clear elspar is followed by a broad zone of palagonite and this in turn

by a very narrow border of clear felspar. Another type of alteration is well shown by the largest phenocryst in the slide, in which traces of the original polysynthetic twinning are still recognisable, but in which the original felspar has been dissolved and replaced by a hyalopilitic aggregate of felspar microlites, grains of ore, and a little glass, resembling the typical groundmass of the rock. Similar but less advanced replacement is shown by other phenocrysts and is accompanied by a marginal segregation of hematite. Many of the felspars and pseudomorphs of palagonite following them contain inclusions of needles of a highly refractive mineral similar to those described in the previous slides (24216--7). Owing to the intense alteration suffered by the felspars, two only were found which could be determined by the Fedoroff method. One was twinned according to the albite, complex albite-carlsbad and manebach laws, and had an anorthite content of sixty per cent. The other, twinned according to the albite and carlsbad laws, showed repeated zoning on (111), ($\bar{1}\bar{1}1$) and (010), and a range of from sixty to seventy per cent. anorthite.

Apart from the felspar phenocrysts and minute grains of a black opaque ore, no other original constituents are determinable, but the slide contains numerous small rectangular pseudomorphs of *brown palagonite* similar to those described in previous slides, except that their rectangular form suggests that they follow felspar rather than ferromagnesian constituents. Many, in fact, afford evidence, in the form of remnants of felspar, that they follow this mineral, unless indeed the small borders and internal patches of felspar are regarded as a secondary product. In other examples, there is no evidence at all, apart from the very inconclusive evidence of form, which enables any conclusion to be drawn as to their ancestry, which must remain an open question.

MICRO-SLIDES 24221—3.

Amygdaloidal andesite.

A porphyritic rock consisting of phenocrysts of plagioclase (labradorite and bytownite) and diopside in a hyalopilitic groundmass, consisting of minute felspar microlites and a few grains of pyroxene in abundant opaque glass, and containing many amygdules filled with chalcedony, opal, lussatite and quartz.

The *felspar* phenocrysts, comprising some forty per cent. of the rock, vary very considerably in size, but may be broadly classified

as an early generation, the average length of which is 2 mm. and a younger generation of stumpy and lath-shaped habit, with an average length of 0.5 mm. The composition of the former, which are very much zoned, ranges from 60 to 80 per cent. anorthite. Both generations appear quite fresh, but frequently contain innumerable grains of an opaque mineral, too small for determination, sometimes arranged zonally and surrounded by a clear margin of felspar of slightly more acid composition. The earlier generation show a tendency to glomeroporphyritic segregation, and in one instance three large crystals interpenetrate to form a stellate aggregate. In eight specimens determined, there was an example each of simple and polysynthetic albite twinning, two of polysynthetic albite and carlsbad twinning, one of polysynthetic albite, carlsbad and complex albite-carlsbad twinning, one of albite-carlsbad twinning, two of polysynthetic albite and carlsbad in combination with baveno (right) twinning, one of acline in combination with polysynthetic albite twinning, and one of normal, parallel and complex on (001) in combination with polysynthetic albite twinning. Six of the eight specimens determined showed well-developed cleavage on (001).

Diopside is represented by several large phenocrysts of idiomorphic contour and average length of 1 mm., but forming in the aggregate less than five per cent. of the volume of the rock. It is very slightly coloured and pleochroic from very pale green ($n\alpha$) to an equally pale brownish-green ($n\gamma$). Several of the crystals are quite fresh, but others have been almost entirely replaced by pale pink opal in which traces of the original pyroxene cleavage are recognisable. The optic angle of four fresh specimens, determined by the Fedoroff method, varied from 54° to 57° , and the extinction of two specimens determined by the same method was 39° and 40° respectively.

The slide contains several pseudomorphs of a pale brown mineral with a refractive index slightly higher than canada balsam and low to moderate birefringence. This substance is similar to the brown palagonite described in connection with previous slides, except that the elongation of the fibres is negative. In this instance the properties suggest *amesite* or a similar optically positive mineral of the chlorite group, of which Larsen and Berman¹ state that the

¹ E. S. Larsen and H. Berman, 'The Microscopic Determination of the non-opaque minerals', *U. S. G. S. Bull.* 848, p. 230, (1934).

acute bisectrix is always normal to the plates (*i.e.*, elongation negative). The average length of the pseudomorphs is 0.3 mm.

The groundmass, which forms approximately 20 per cent. of the rock, consists of minute felspar microlites, too small for determination, and a few grains of pyroxene, also too small for determination but with properties similar to those of the diopside phenocrysts, in abundant opaque glass.

The remaining 30 per cent. of the rock consists of amygdules of irregular form, varying in length from 0.5 to 4 mm., and filled with various forms of amorphous and crystalline silica. A few consist almost entirely of chalcedony in beautiful radiating fibres, but many are of great complexity. In most instances, the initial lining of the vesicle is a narrow band of a pale yellowish fibrous mineral which is responsible for the colour of the unbroken amygdules in the hand specimen (*vide* page 181). This mineral has a refractive index slightly higher than canada balsam, negative elongation, low birefringence, and appears identical with the mineral occurring in the pseudomorphs already described. This narrow lining is usually followed by a still narrower layer of a colourless to cream-coloured fibrous mineral with positive elongation, low birefringence, and a refractive index appreciably higher than the layer of opal which follows it. These properties agree with those of *lussatite*, which Sir L. L. Fermor¹ described from the basalts of Bhusawal. This is followed by a narrow band of pale reddish-brown opal growing as a mamillated encrustation from the surface of the lussatite layer. In most cases this band of opal is of greater width than either of the preceding layers; the average is 0.1 mm. but occasionally the thickness rises to 0.2 mm., and still more rarely the entire amygdule, apart from the initial lining of pale yellowish-brown mineral, is composed of this substance. In most instances, a narrow layer of opal is followed by a layer of *chalcedony* some 0.4 mm. in width, and consisting of fibres with negative elongation arranged radially from nodes situated on the surface of the surrounding opal. In some cases this is followed by a second layer of chalcedony consisting of still smaller fibres arranged in aggregates resembling hemi-spherulites, radiating from nodes situated on the surface of the layer of coarser-grained chalcedony. In many instances this extends to the centre of the amygdule, where the mutual interference of neighbouring aggregates produces a series

¹ *Rec. Geol. Surv. Ind.*, LVIII, pp. 169-170, (1925).

of honeycomb sutures. In other cases the final product of crystallisation is a mosaic of mutually interfering grains of *quartz* of varying optical orientation, and in such cases, the radial aggregates of *chalcedony* which surround it have developed crenulated semi-circular outlines.

The texture of this rock is illustrated by figure 3 of Plate 34.

MICRO-SLIDES 24224—5.

Micro-hornblende-gabbro.

A holocrystalline rock with rudimentary hornfels structure, and consisting of approximately equal proportions of hornblende and feldspar (bytownite) with a few remnants of rhombic pyroxene and between one and two per cent. ore. Neither the hornblende nor the feldspar have developed idiomorphic contours, and locally the slide consists of an equigranular mosaic of the two minerals, and in this portion of the slide the average grain size is 0.5 mm. Elsewhere, the hornblende crystals attain a length of approximately 1 mm., and here the feldspar laths occupy the interstices between the large hornblende crystals. A few large feldspars, approaching 2 mm. in length, also occur but such large crystals are exceptional.

The *feldspars* are slightly cloudy due to the inclusion of minute particles, which, under the high power, appear as irregular grains of a transparent colourless mineral with high refractive index. The composition of ten specimens determined, lay between 75 and 90 per cent. anorthite, but one large crystal contained an irregular intergrowth, sub-parallel to (001), of feldspar of intermediate composition (45 per cent. An.), forming approximately one-fifth of the total bulk of the crystal. The other large crystals of feldspar also frequently show small irregular patches with lower extinction and refractive index than the host and apparently of the same nature, but too small for complete determination. All the ten specimens determined were twinned on (010), in five instances in combination with pericline twinning, and eight specimens showed well-developed cleavage on (001) while two also showed cleavage on (010).

The *hornblende* is strongly pleochroic from pale yellowish-brown ($n\alpha$) to deep brown ($n\beta$) and deep, slightly greenish-brown ($n\gamma$). It is optically negative with an optical angle of approximately 80° and a maximum birefringence of 0.022. Prismatic cleavage

is well developed and the mineral appears quite fresh. Inclusions of irregular grains of ore are common.

In slide 24224 there are several grains of *rhombic pyroxene* occurring in one small aggregate approximately 1 mm. in diameter and interspersed with grains of felspar. The individual grains are of irregular form and too small (0.1 to 0.2 mm.) for complete determination. The mineral has high refringence and birefringence and is pleochroic from pale greenish-grey ($n\gamma'$) to pale pink ($n\alpha'$).

Small grains of ore, black but with small white flecks by reflected light, are common and in rare instances attain a diameter of 0.2 mm., but the average size is not more than 0.1 mm. They are almost invariably enclosed in crystals of hornblende.

MICRO-SLIDE 24226.

Micro-hornblende-gabbro (marginal facies).

In the hand specimen, this rock has a slightly foliated schistose appearance, which, however, is not recognisable in thin section. Texturally it is similar to the two slides last described, but in this rock hornblende is almost entirely replaced by aggregates of *epidote* and *chlorite*. The former mineral occurs both in irregular grains, of approximately 0.1 mm. in diameter, in association with chlorite, and in large fibrous aggregates approaching 2 mm. in length. In both cases the size of the individual grains or fibres is too small to permit complete optical determination. The chlorite is also fibrous and is pleochroic from pale yellow ($n\alpha$) to pale green ($n\gamma$) and polarises in the abnormal 'ultra blue' interference colour characteristic of penninite.

MICRO-SLIDES 24227—8.

Weathered hornfels.

In the hand specimen, these rocks are very friable and are characterised by the presence of abundant kaolin. In thin section, they are so fragmentary that the structure is only recognisable in small areas which have resisted disintegration. Such areas, particularly in slide 24227, show pronounced hornfels structure and are similar both structurally and in mineralogical composition to the hornfels previously described (micro-slides 24199—201). These remnants

consist of an equigranular mosaic of *quartz* grains containing irregular aggregates of minute quartz grains and *kaolin* and numerous nests of *white mica*. The average diameter of the quartz grains forming the bulk of the rock is 0.4 mm., and the aggregates of kaolin and quartz are of approximately the same dimensions. The nests of white mica are some 0.8 mm. in diameter and the individual flakes of mica attain a length of 0.3 mm. As in the case of the hornfels previously described (*vide* pages 173-174) these aggregates of mica are very reminiscent of the disintegration product of andalusite or cordierite, and it is thought that they are either pseudomorphous after one of these minerals or represent the products of low grade metamorphism which was not sufficiently intense to result in their crystallisation.

In addition to these minerals the slides contain much disseminated *hematite*.

MICRO-SLIDE 24229.

Quartz-sericite-schist.

A highly foliated, fine-grained rock, consisting of lenticular aggregates of granular quartz alternating with laminae of sericite, containing small needles of tourmaline and zoisite and small crystals of garnet and grains of quartz, which enclose and sweep round the quartz aggregates.

The *quartz* lenses consist of equigranular mosaics of irregular grains with an average diameter of 0.2 mm., and apart from an occasional flake of sericite are free from admixture with other minerals. Introduction of a sensitive plate (1st order red) reveals that many of the grains have similar optical orientation, suggesting that they have originated by the granulation of larger grains or crystals.

The intervening laminae, rich in *sericite*, contain much very fine-grained material, irresolvable even under high powers, but in addition to the flakes of sericite, the average length of which is approximately 0.4 mm., contain small needles of *tourmaline*, 0.15 mm. in length and pleochroic from pale yellow ($n\alpha$) to greenish-brown ($n\gamma$); needles of *zoisite*, 0.3 mm. in length, and including representatives with both positive and negative elongation, and polarising in abnormal blue interference tints; small crystals of pale pink *garnet*, ranging from 0.1 to 0.4 mm in diameter, and minute grains of *quartz* averaging less than 0.1 mm. in diameter.

CHAPTER VI.

THE LETPANDAUNG AND ASSOCIATED EXTRUSIVE ROCKS.

The geology of this area, one inch to one mile sheet 84.N/4, is shown, on the reduced scale of one inch to two miles, in Plate 25. The alluvial belt, west of the Chindwin river, which in sheet 84.O/1 is constricted by the Salingyi uplands, again expands in this sheet where the alluvium of the Chindwin itself merges with that of its tributary the North Yama Chaung. The area north of this stream was not mapped by me but it has received systematic treatment at the hands of Messrs. Pinfold, Day, Stamp and Chhibber¹ and, more recently by Professor Burri and Dr. Huber.² The gently rising ground south-west of the alluvial belt, is occupied by a somewhat sandy facies of the Pegu series, but owing to the unbroken nature of the country and the development of 'Plateau Gravel' and 'Plateau Red Earth', these rocks are poorly exposed. In the alluvial belt itself, three small inliers of Irrawaddian rocks were mapped by my colleague Mr. V. P. Sondhi, who completed the mapping of this sheet after my transfer to other duties.

Two and a half miles south-west of the town of Monywa (22° 7' : 95° 8') and immediately south of the village of Kyaungywa, rise the conspicuous Letpandaung hills. Their form is shown by the panoramic photograph given as figure 2 of Plate 27, taken looking west from one mile west of the village of Ywashe (22° 6' : 95° 7'). Externally they have the appearance of a series of flat fluted cones, but on entering by a gap carved by a small stream emerging from their north-eastern margin, a large crateriform basin is seen which also appears to have been much modified by denudation. The hills are composed of rhyolites which in the northern portions have the appearance of compact flows but which in the southern and eastern portions consist of a chaotic assemblage of large blocks. Both varieties have undergone pronounced fumarolic and hydrothermal alteration, locally accompanied by the introduction of the copper ores malachite and chalcantinite. In the past, attempts have been made

The rhyolites of the Letpandaung hills.

¹ E. S. Pinfold, A. E. Day, L. D. Stamp and H. L. Chhibber, *loc. cit.*

² C. Burri and H. Huber, *loc. cit.*

to exploit these minerals on a commercial scale and the emplacements of heavy crushing machinery are still to be seen at the south of the hills. As no statistics are available in the revenue offices it is presumed that no commercial output was obtained, and Dr. J. Coggin Brown, who accompanied the author when these rocks were examined, is of the opinion that the proportion of ore is too small for profitable exploitation.

The compact rhyolites from the northern portion of the hills (micro-slide 24231) are of purple colour and contain many small aggregates, approximately one millimetre in length, of a white friable substance. They break with a splintery fracture and in the hand specimen are for the most part compact but contain several cavities, the largest of which is approximately three cubic centimetres in volume, partially filled by sublimated encrustations of hematite. The blocks of lava forming the south-eastern portions of the hills (micro-slide 24230) consist of a very decomposed rock, fawn in colour and containing large irregular and sub-rectangular pseudomorphs of white kaolin, which, in the hand specimen give the rock a brecciated appearance. These pseudomorphs vary from two millimetres to one centimetre in length and form approximately 25 per cent. of the rock. In addition, smaller pseudomorphs of a greenish-brown mineral, averaging three millimetres in diameter, are abundant. They show moderately well-developed basal cleavage, and transverse sections are sub-hexagonal in form. Longitudinal sections show vertical striations suggesting highly developed prismatic cleavage in the original mineral.

The hills are entirely surrounded by alluvium and there is no direct evidence of their age, but I see no reason for postulating their recent or sub-recent age. I have already referred to their fluted appearance, suggesting advanced denudation, and the small stream emerging from their north-eastern margin is mature in form having reached, apparently, the base level of erosion. Owing to their hydrothermal alteration, the rocks are probably little susceptible to chemical weathering as the products of hydrothermal action in such rocks are similar to the products of weathering, but they are susceptible to mechanical weathering, which, however, in a region of such low rainfall (approximately 20 inches per year), must be a slow process. I consider, therefore, that their morphological form is presumptive evidence that they are not of sub-recent origin.

Similar rhyolitic rocks form the small hill situated one mile to the north-west of the Letpandaung hills, where, also, they are entirely surrounded by alluvium, and again occur in two small elevated outcrops occurring at the eastern margin of the Pegu outcrop. Here, their relationships to the Pegu sediments are obscured by 'Plateau Gravel' and the products of their own denudation, but I formed the opinion that they are younger than the Pegu sediments.

Immediately south of the North Yama Chàung, four miles to the north-north-west, are two conspicuous conical hills rising from the Pegu series on the west and surrounded on the other sides by alluvium, these outcrops were mapped by my colleague Mr. V. P. Sondhi, and I have no specimens of the rocks. They are described by Messrs. Pinfold, Day, Stamp and Chhibber¹ as being composed of bluish-grey rhyolites, rhyolitic breccias and indurated tuffs, but no conclusions as to their age were stated by these authors.

To the immediate south of the confluence of the North Yama Chaung and the Chindwin river, a small hill rises from the alluvium to a height of 521 feet. This hill was mapped by myself, and consists of compact rhyolitic tuffs with intercalated silicified sandstones. In the field, the latter were regarded by me as being of Pegu age, but since Mr. Sondhi has mapped inliers of Irrawaddian rocks in the alluvium to the south-west, they are probably of Irrawaddian age. The tuffs consist of compact, splintery rocks of brick-red colour, containing numerous small crystals of somewhat smoky quartz and pellucid chips of light grey colour. Microscopic examination (micro-slide 24232) indicates that the rock has undergone secondary silicification. If these rocks are of Irrawaddian age, as the interbedded silicified sandstones would suggest, the other rhyolitic rocks of this area may with great probability be assigned to the same age.

Petrological Description of the Letpandaung and Kyaukmyet Extrusive Rocks.

MICRO-SLIDE 24230.

Rhyolite.

A very decomposed rock of pale brown colour and containing large irregular and subrectangular pseudomorphs of white kaolin, which,

¹ E. S. Pinfold, A. E. Day, L. D. Stamp and H. L. Chhibber, *loc. cit.*, p. 169.

in the hand specimen, give the rock a brecciated appearance. These pseudomorphs vary from 2 mm. to 1 cm. in length and form approximately 25 per cent. of the rock. In addition, smaller pseudomorphs of a greenish-brown mineral, averaging 3 mm. in diameter, are abundant. They show moderately well-developed basal cleavage, and transverse sections are subhexagonal in form. Longitudinal sections show vertical striations suggesting highly developed prismatic cleavage in the original mineral.

In thin section, the rock is seen as a holocrystalline porphyritic rock containing quartz phenocrysts and pseudomorphs of kaolin and chlorite in a micro-granitic groundmass.

The *quartz phenocrysts* average 1 mm. in diameter and are characterised by pronounced corrosion. They are of sporadic occurrence and form less than two per cent. of the rock.

Subrectangular and polygonal aggregates of *kaolin*, varying from 1 to 4 mm. in length, are abundant. Their form is that of idiomorphically developed feldspar phenocrysts and in some instances, concentric banding suggests zonal structure in the original mineral, while in others, a longitudinal banding suggests original polysynthetic twinning. These features, combined with the characteristic form, leave little doubt that they are pseudomorphs after feldspar phenocrysts.

Colourless *chlorite* occurs in fibrous aggregates containing small lenticular grains of a greenish-brown, almost opaque mineral. Several of the aggregates show the very characteristic subhexagonal outlines of transverse sections of hornblende while another has the form of a longitudinal section [parallel to (100)] of a monoclinic or rhombic mineral with a development of longitudinal pinacoids and prisms. In the latter, the chlorite fibres and lenticles of brown mineral are arranged longitudinally and the chlorite extinguishes parallel to the pinacoid face. It has positive elongation and low birefringence. The small lenticular grains of greenish-brown mineral, associated with chlorite in these aggregates, appear opaque under low powers but under high powers and on introduction of the condenser appear translucent. They are characterised by high relief, weak pleochroism from greenish-brown to golden-brown, high birefringence and very strong dispersion. These properties suggest epidote, but the absorption appears too strong for such minute grains of this mineral. The relief and birefringence, on the other hand, appear too low for brookite or other titaniferous minerals. Many

of the chlorite aggregates containing this mineral show fine-grained, less perfectly individualised margins, suggestive of reaction rims, from which and from their form, they are thought to be pseudomorphous after a mafite, probably hornblende. The largest of these pseudomorphs seen in the thin section is 4.5 mm. in length and the average length is approximately 2 mm.

MICRO-SLIDE 24231.

Rhyolite.

A hard somewhat splintery rock of purple colour containing many small aggregates, approximately 1 mm. in length, of a white friable substance. The rock is for the most part compact, but contains several cavities, the largest of which is approximately 3 ccs. in volume, partially filled with hematite in sublimated incrustations.

Under the microscope, the rock appears much more porous than in the hand specimen, but this is probably partially due to the removal of white powdery aggregates, which are poorly represented in the thin section, by the grinding process. It is a fine-grained felsitic rock in which primary glass, if originally present, is entirely devitrified. A few fine-grained aggregates of granular quartz and kaolin are preserved and average approximately 1 mm. in length. They are subrectangular in form and undoubtedly pseudomorphs after felspar, which, if the subrectangular cavities seen in the slide were formerly occupied by similar aggregates of kaolin, formed originally approximately five per cent. of the rock.

Quartz phenocrysts are absent from the slide but this mineral is abundant in the groundmass and also locally as a secondary mineral, in aggregates with wavy extinction and occasionally well-defined radial structure.

Small flakes of colourless mica, averaging 0.05 mm. in length, are abundant in the groundmass, and also in association with hematite in porous aggregates of the latter mineral.

The aggregates of hematite, average 0.5 mm. in diameter and are composed of irregular grains approximately 0.05 mm. in diameter, with interstitial cavities, and very frequently abundant flakes of colourless mica. Hematite occurs also as small grains of about the same magnitude, locally dispersed throughout the groundmass.

MICRO-SLIDE 24232.

Rhyolitic tuff.

A very compact splintery rock of brick red colour and containing numerous small fragments of somewhat smoky quartz and a number of small subrectangular aggregates of a white friable substance resembling kaolinised felspar.

Microscopically, the rock is seen to consist of devitrified and partially kaolinised glass with a refractive index equal to n_{α} quartz, containing splinters of quartz and pseudomorphs of kaolin and quartz after felspar. The devitrified glassy groundmass is crowded with inclusions of *hematite* in the form of disseminated dust, which is responsible for the red colour of the rock in the hand specimen. Streaky patches of devitrified glass in which such inclusions are less numerous are suggestive of flow.

The *quartz* fragments range from 0.4 to 0.6 mm. in length and form in the aggregate approximately five per cent. of the rock. A few show sub-idiomorphic contours but the majority are irregular and splintery in form. Several show inclusions of minute negative crystals, in some cases with beautifully developed bipyramidal and prismatic form, and with their major axes coincident with the principal crystallographic axis of the host. They are filled with some substance of much lower refractive index than the host, and since no Brownian movement is detectable, it is probably gaseous.

A few aggregates of *granular quartz* and *kaolin* appear from their form to be pseudomorphous after felspar, and several cavities of similar shape may have been filled by these substances prior to the grinding of the slide. The pseudomorphs and cavities are together subordinate both in number and volume to the fragments of quartz.

CHAPTER VII.

THE IGNEOUS HISTORY OF THE REGION AND OTHER GENETIC PROBLEMS.

In attempting to elucidate the igneous history of this region, it is obvious that the problem cannot be divorced from some consideration of other igneous manifestations of Tertiary and Recent age in Burma, and, more particularly from some reference to the igneous rocks of the Twindaung region lying on the same structural line and to the immediate north of the area mapped by me. For detailed information relating to the latter region reference should be made to the papers by Messrs. Pinfold, Day, Stamp and Chhibber¹ and by Professor Burri and Dr. Huber², already cited. Recently a comprehensive summarised account of igneous activity in Burma has been given by Dr. H. L. Chhibber³, who recognised four petrogenetic cycles :—

‘ 1. Early Palaeozoic, comprising the granite clan with effusive and hypabyssal representatives.

2. Late Cretaceous-early Eocene, marking the outbursts of the rocks of the peridotitic and granite clans.

3. Pliocene—pillow lavas, basic volcanic rocks and tuffs.

4. Late Pliocene, Pleistocene and Recent, comprising predominantly rocks of the basaltic and andesitic clans, with subordinate rhyolites, etc.’

In so far as this scheme contains no reference to Oligocene and Miocene igneous activity, it requires modification in view of my own work in the Pakokku and southern portion of the Lower Chindwin districts. From the above accounts of this area it will be seen that contemporaneous volcanic activity in Pegu times has been clearly demonstrated by the presence of interbedded tuffs in the Shinmadaung area (*vide* pages 135-137 *supra*) and of interbedded andesites in the Ingyintaung area (page 180). In his latest work, also, Dr. Chhibber makes no reference to the contemporaneous volcanic rocks of Pondaung (Upper Eocene) age in the Shwebo hills which are referred to by his collaborators in a former work⁴ in the following terms :—

‘ Rocks of Pondaung age, similar lithologically to those cropping out in the Medin inlier, occur in the Shwebo Hills, an extensive inlier to the north, but on the

¹ E. S. Pinfold, A. E. Day, L. D. Stamp and H. L. Chhibber, *loc. cit.*

² C. Burri and H. Huber, *loc. cit.*

³ H. L. Chhibber, ‘ The Geology of Burma ’, London, (1934) pp. 286-507.

⁴ E. S. Pinfold, A. E. Day, L. D. Stamp and H. L. Chhibber, *loc. cit.*, p. 154.

same tectonic line as Myaing and Medin. Here there are interbedded lava flows, agglomerates and ash-beds *indicating volcanicity contemporaneous with the deposition of the Pondaung beds.*¹

I have previously² given reasons for believing that the activity of Mount Popa, also on the same tectonic line as the region here considered, which Dr. Chhibber³ classifies as late Pliocene and Pleistocene, began in Pegu times, and in view of the above-mentioned facts I would propose the following additions to Dr. Chhibber's classification of Tertiary to Recent igneous manifestations in Burma, the sites of which are shown on the topographical map given as Plate 24. The early Eocene manifestations listed by Dr. Chhibber appear to belong to the Cretaceo-Eocene cycle and are not included in this classification.

PONDAUNG (Upper Eocene).

Shwebo Hills.—Lava flows, agglomerates and ashes.⁴

SHWEZETAW (Lower Oligocene).

Pakokku district.—Interbedded tuffs and associated andesites and andesitic tuffs of the Shinmadaung area.*

OLIGOCENE—MIOCENE.

Lower Chindwin district.—The interbedded andesites of the Ingyint-aung region.*

UPPER MIOCENE.

Mingyan district.—The early activity of Mount Popa, manifested by interbedded tuffs at Kabat (21° 3': 95° 17').⁴

POST-MIOCENE (AGE UNCERTAIN).

Pakokku district.—Diabase intrusion of the Shinmadaung area* (see page 205 below).

Lower Chindwin district.—The gabbro intrusion of the Salingyi uplands, the micro-hornblende-gabbro of the Powintaung area, and the basalt intrusion of Linzagyet.*

¹ The italics are mine.

² C. T. Barber, *loc. cit.*, p. 13.

³ H. L. Chhibber, *loc. cit.*, p. 472.

⁴ E. S. Pinfold, A. E. Day, L. D. Stamp and H. I. Chhibber, *loc. cit.*, p. 154.

* Denotes occurrences which are the subject of this paper.

PLIOCENE.

Lower Chindwin district.—The interbedded rhyolitic tuffs of the Kyaukmyet hills and probably the rhyolites and rhyolitic tuffs of the Letpandaung and associated hills.*

Shwebo district.—(a) Kabwet area :—highly altered pillow lava, (b) basic volcanic rocks.¹

Lower Chindwin and Myingyan districts.—Ash and tuff deposits interbedded with the Irrawaddy series.¹

LATE PLIOCENE AND PLEISTOCENE. (After Chhibber.)¹

Jade Mines area.—Hornblende-andesite and picrite-basalts. Siliceous breccia and agglomerate.

Lower Chindwin region.—Picrite-basalts, olivine-basalts, hypersthene-basalt, tachylite, nepheline-tachylite, hornblende-andesite, hypersthene andesite, acid andesite, rhyolite, rhyolite flow breccia, ejected blocks of dolerite, epidiorite and amphibolite, quartz-porphry, muscovite porphyry and hornblende-granite-porphry, peridotites and perknites. Augite-diorite and quartz-diorite, volcanic ashes and tuffs.

Mount Popa region.—Older andesites comprising pyroxene-andesite, augite-biotite-andesite, acid spherulitic andesite and biotite andesite with hauyne. Silicified tuff and rhyolites. White silicified tuffs and rhyolites, basaltic ashes and tuffs, hornblende augite andesite, hornblende-andesite. Olivine-basalt, glassy hypersthene-andesite.

Prome district.—Olivine-dolerite.

Narcondam.—Hornblende-andesite and agglomerate.

Barren Island.—Scoriae, ash, agglomerate and olivine-basalt.

Shwebo and Mandalay districts.—Tescheneite, analcite-dolerite, olivine-dolerite, olivine-basalt (mugearite) and tachylite.

Thaton district.—Rhyolites and rhyolite tuffs.

Teng-Yueh area, south-west Yunnan.—Pyroxene-andesite, hornblende-andesite, augite-olivine-andesite and olivine-basalt.

Lai Han Hun, Northern Shan States.—Olivine-basalt.

Medaw Island, Mergui Archipelago.—Olivine-basalt.

¹ H. L. Chhibber, *loc. cit.*, p. 471-472.

* Denotes occurrences which are the subject of this paper.

RECENT (after Chhibber¹).

- Jade Mines area.*—Olivine-basalt and siliceous agglomerate.
Lower Chindwin region.—Ashes and tuffs of the explosive craters; some flows of basalt. The basalt plateau of Sonetaung (*vide* page 140 *supra*) should probably be included here (C. T. B.).
Mount Popa region.—Latest flows of olivine-basalt and andesite, later ashes with bombs of vesuvianite-basalt and andesite.
Barren Island.—Active, within historic times.
Teng-Yueh area.—Olivine-basalts of She-toe-Shan.

Turning now to a more detailed consideration of the igneous history of the region mapped, it appears that the igneous rocks belong to a late Eocene-Pliocene cycle of activity which may be correlated with the rise of the Arakan Yoma, which Dr. Cotter² states constituted a continually rising geo-anticline during this period, and the crumpling of the central portions of the great Tertiary basin giving rise to the four tectonic lines already described (*vide* page 122) and which are indicated in the map given as Plate 24. This late Eocene-Pliocene cycle appears to have been initiated by a paroxysmal volcanic outburst giving rise to the interbedded agglomerates, ashes and lavas of Pondaung (Upper Eocene) age in the Shwebo hills, and continued in Shwezetaung (Lower Oligocene) times by similar volcanic manifestations represented by the extrusive rocks of the Shinmadaung area in the region under review. This volcanic activity may with great probability be correlated with the earth movements giving rise to the unconformity which Mr. Lepper, on palæontological grounds, places at the base of the Oligocene. There is abundant evidence that in this region the activity was heralded by a paroxysmal phase giving rise to the interbedded tuffs which are unquestionably of Shwezetaung (Lower Oligocene) age. The first products of the activity appear to have been the lithic tuffs and the accumulations of boulders and fragments of country rock which are still preserved at the foot of Taungtha hill (*vide* pages 138-139) which in my opinion owe their origin to the shattering by the uprising magma of the ancient crystalline floor which all observers believe to be very near the surface in this region. This paroxysmal phase appears to have been followed by the extrusion of the andesites which was followed or punctuated by phases of violent activity giving

¹ H. L. Chhibber, *loc. cit.*, pp. 471-472.

² G. de P. Cotter, *loc. cit.*

rise to the andesitic tuff cones whose origin may be traced to the temporary blocking of the volcanic conduits by congealed viscous magma. The composition of the felspars of the tuffs is slightly more acid than that of those of the andesites themselves, and it will be recalled also that the core of the tuff cones is composed of blocks of tuffaceous lava of more rhyolitic affinities, both of which phenomena suggest a progressive decrease in the basicity of the magma. The intense hydrothermal alteration which the andesitic rocks have undergone may possibly be due to the subsequent intrusion of the diabase, or more probably, since it is so widespread and has given rise to quartz-epidote rocks in the neighbourhood of Kabauk (*vide* page 138), two and a quarter miles distant from the diabase intrusion, to the auto-metamorphism of the andesites by the hydrothermal vapours which were the final mobile products of the consolidation of the magma.

The next episode in the igneous history of this region appears to have been the extrusion of the andesite flow of the Ingyintaung area. The vesicular nature of the surface of this outcrop indicates that it is indeed a flow and not an intrusion, and occurring as it does immediately below the Miocene fossil horizon of Maukthayet, its age may be fixed with some precision as Upper Oligocene or Lower Miocene. The fact that the lowest sedimentary rock exposed, which rests directly on the andesite, is a conglomerate suggests that the extrusion may be correlated with the earth movements responsible for the unconformity which Mr. Lepper, on palæontological grounds, places in the Upper Oligocene (*vide* page 125). Like the andesites of the Shinmadaung area, these rocks have undergone pronounced hydrothermal alteration, resulting in the 'palagonitisation' of the mafites and the partial replacement of the felspars, and, judging from the sequence of minerals in the amygdules, at a later stage in silicification. It is an interesting speculation to what extent the silicification of the fossil-wood which is so abundant in the Irrawaddy series may also be attributed to the final hydrothermal waters of the magmas which produced this and similar silicified andesites, as for example at the southern margin of Mount Popa,¹ of Tertiary age in Upper Burma.

The next phase in the igneous history of this region was probably the intrusive one, represented by the gabbro intrusion of the Salingyi

¹ H. L. Chhibber, 'Igneous Rocks of the Mount Popa Region, Burma', *Trans. Min. Geol. Inst. Ind.*, XXI, pp. 240 and 307, (1927).

Uplands, the micro-hornblende-gabbro intrusion of the Powintuang area, the basalt intrusion of Linzagyet, and, possibly by the diabase intrusion of the Shinmadaung area. In the case of the first three mentioned intrusions, there is definite evidence of the metamorphism of the Pegu sediments, and they must, therefore, be of post-Pegu age. How much later is an open question, but if Irrawaddian sediments had also been indurated by metamorphism it is probable that they also would have been preserved. I am inclined, therefore to correlate the intrusive phase with the folding which produced the pre-Irrawaddian unconformity (*vide* page 125). Whether there is any justification for subdividing the intrusive manifestations into a phase of major intrusion, represented by the Salingyi complex, and a later phase of minor intrusion represented by the Powintuang and Linzagyet intrusions, the field evidence is inadequate to decide. Whether, also, the Shinmadaung diabase intrusion should be assigned to a post-Pegu age is also doubtful. No contact with the Pegu sediments was observed, but fragments of variolite, which at one point occurs at the contact between the diabase and the andesite, are present in the lithic tuffs, which are of Oligocene age. If, as seems probable, the variolite is a chilled margin of the diabase, the intrusion of the latter must have been pene-contemporaneous with the extrusion of the andesites and tuffs.

Another problem to which the field evidence gives no certain answer is the age of the keratophyres which occur at the western margin of the Salingyi complex. From the fact that towards the contact with the gabbro they have undergone epidotisation and structural alterations, I am inclined to regard them as older than the gabbro, but, as stated above, the age of the gabbro itself is by no means accurately known.

Another extrusive phase is represented by the rhyolites and rhyolitic tuffs of the Letpandaung and Kyaukmyet areas. From the presence of interbedded silicified sandstones, I believe the latter to be of Pliocene age, and in the absence of direct evidence, suggest that their similarity to the Letpandaung rocks is sufficient justification for assigning them also to this age. Whether one sees in these lavas and tuffs evidence of a closing volcanic episode to the late-Eocene-Pliocene igneous cycle, or the initiation of a new Pliocene-Recent cycle which was characterised by great activity in the Twin-daung area to the north¹, and in the Mount Popa region to the

¹ *Vide* E. S. Pinfold, A. E. Day, L. D. Stamp and H. L. Chhibber, *loc. cit.*

south¹, is a matter of opinion. There is, however, some evidence in the Mount Popa region of quasi-continuous volcanic activity from Miocene to sub-Recent times, and, if my views on this region are correct, there is probably no justification for dividing the igneous activity of the Pakokku and Lower Chindwin districts into two cycles of late Eocene-Miocene, and Pliocene-Recent age. If eventually, this is done, the basalt flow of Sonetaung (Shinmadaung area) should probably be assigned to a late phase of the latter cycle.

The results of the analyses by Dr. P. Bearth of the olivine-gabbro, gabbro, hornblende-granulite and quartz-oligoclase-bearing rock (hybrid-rock) of the Salingyi complex, and the

Chemical considerations. basalt of Linzagyet, are given in tables 1 to 5 below, in which the molecular proportions and normative values are also incorporated. In view of the pronounced hydrothermal alteration undergone by the andesites, and to a lesser extent the weathering, and in some cases the epidotisation of the keratophyres, it was considered that these rocks were unsuitable for analysis.

TABLE 1.—*The Analysis of the Olivine-gabbro (Micro-slides 24178-80)*

—	Per cent.	Molecular proportions.	—	Norm Per cent.
SiO ₂ . . .	43.51	0.725	Orthoclase . .	1.11
TiO ₂ . . .	0.55	0.007	Albite . . .	6.81
Al ₂ O ₃ . . .	24.69	0.242	Anorthite . .	62.55
Fe ₂ O ₃ . . .	1.55	0.010	Nepheline . .	0.75
Cr ₂ O ₃ . . .	0.03	..	Diopside—	
FeO . . .	4.73	0.066	CaO. SiO ₂ . .	4.99
MnO . . .	0.10	0.001	MgO. SiO ₂ . .	3.40
MgO . . .	7.38	0.184	FeO. SiO ₂ . .	1.19
CaO . . .	15.18	0.271	Olivine—	
Na ₂ O . . .	0.96	0.015	2 MgO. SiO ₂ . .	10.50
K ₂ O . . .	0.24	0.002	2 FeO. SiO ₂ . .	4.08
H ₂ O+ . . .	0.75	0.041	Magnetite . .	2.32
H ₂ O— . . .	0.20	0.011	Ilmenite . . .	1.06
P ₂ O ₅ . . .	0.18	0.001	Apatite . . .	0.34
CO ₂ . . .	Nil	..	Water . . .	0.95
S . . .	Nil	..		
TOTAL . .	100.05	..	TOTAL . .	99.87

SYMBOL (C. I. P. W.) II. 5. 5. 5.
NAME :—Hessose.

¹ Vide H. L. Chhibber, *loc. cit.*

TABLE 2.—*The Analysis of the Gabbro (Micro-slides 24181-4).*

—	Per cent.	Molecular proportions.	—	Norm Per cent.
SiO ₂ . . .	47.14	0.785	Orthoclase . . .	1.67
TiO ₂ . . .	1.26	0.015	Albite . . .	12.05
Al ₂ O ₃ . . .	16.34	0.160	Anorthite . . .	37.25
Fe ₂ O ₃ . . .	1.86	0.011	Diopside—	
Cr ₂ O ₃ . . .	0.05	..	CaO. SiO ₂ . . .	14.85
FeO . . .	5.43	0.075	MgO. SiO ₂ . . .	10.70
MnO . . .	0.12	0.002	FeO. SiO ₂ . . .	2.77
MgO . . .	10.20	0.255	Hypersthene—	
CaO . . .	14.87	0.265	MgO. SiO ₂ . . .	2.80
Na ₂ O . . .	1.39	0.023	FeO. SiO ₂ . . .	0.79
K ₂ O . . .	0.33	0.003	Olivine—	
H ₂ O+ . . .	1.09	0.061	2MgO. SiO ₂ . . .	8.40
H ₂ O— . . .	0.10	0.006	2FeO. SiO ₂ . . .	2.24
P ₂ O ₅ . . .	0.11	0.001	Magnetite . . .	2.55
CO ₂ . . .	Nil	..	Ilmenite . . .	2.28
S . . .	Nil	..	Apatite . . .	0.34
			Water . . .	1.19
TOTAL .	100.29	..	TOTAL .	99.88

SYMBOL (C. I. P. W.) III. 5. 5. 5.
Name :—Kedabekase.

TABLE 3.—*The Analysis of the Hornblende-granulite (Micro-slides 24195-7).*

—	Per cent.	Molecular proportions.	—	Norm Per cent.
SiO ₂ . . .	47.72	0.795	Quartz . . .	7.44
TiO ₂ . . .	2.54	0.031	Orthoclase . . .	1.11
Al ₂ O ₃ . . .	16.89	0.166	Albite . . .	13.62
Fe ₂ O ₃ . . .	5.86	0.036	Anorthite . . .	38.36
Cr ₂ O ₃ . . .	Nil	..	Diopside—	
FeO . . .	7.00	0.097	CaO. SiO ₂ . . .	5.80
MnO . . .	0.08	0.001	MgO. SiO ₂ . . .	4.10
MgO . . .	5.81	0.147	FeO. SiO ₂ . . .	1.19
CaO . . .	10.71	0.191	Hypersthene—	
Na ₂ O . . .	1.63	0.026	MgO. SiO ₂ . . .	10.60
K ₂ O . . .	0.16	0.002	FeO. SiO ₂ . . .	2.77
H ₂ O+ . . .	1.03	0.056	Magnetite . . .	8.35
H ₂ O— . . .	0.34	0.019	Ilmenite . . .	4.71
P ₂ O ₅ . . .	0.17	0.001	Apatite . . .	0.34
CO ₂ . . .	Nil	..	Water . . .	1.37
S . . .	Nil	..		
TOTAL .	99.94	..	TOTAL .	99.76

SYMBOL (C. I. P. W.) III. 5. 4. 5.
NAME :—Auvergnose.

TABLE 4.—*The Analysis of the Quartz-oligoclase-bearing hybrid rock (Micro-slides 24185-7).*

—	Per cent.	Molecular proportions.	—	Norm Per cent.
SiO ₂ . . .	76.48	1.274	Quartz . . .	49.86
TiO ₂ . . .	0.57	0.007	Orthoclase . . .	2.22
Al ₂ O ₃ . . .	11.65	0.114	Albite . . .	23.58
Fe ₂ O ₃ . . .	1.70	0.011	Anorthite . . .	18.07
Cr ₂ O ₃ . . .	Nil	..	Diopside—	
FeO . . .	0.66	0.009	CaO. SiO ₂ . . .	0.81
MnO . . .	0.02	..	MgO. SiO ₂ . . .	0.70
MgO . . .	0.30	0.007	FeO. SiO ₂ . . .	..
CaO . . .	4.70	0.084	Wollastonite . . .	0.58
Na ₂ O . . .	2.80	0.045	Magnetite . . .	2.09
K ₂ O . . .	0.45	0.004	Hematite . . .	0.23
H ₂ O+ . . .	0.23	0.011	Ilmenite . . .	1.06
H ₂ O— . . .	0.10	0.006	Apatite . . .	0.67
P ₂ O ₅ . . .	0.32	0.002	Water . . .	0.33
CO ₂ . . .	Nil	..		
S . . .	Nil	..		
TOTAL . . .	99.98	..	TOTAL . . .	100.29

SYMBOL (C. I. P. W.) I. 3. 4. 5.
NAME :—Vulcanose.

TABLE 5.—*The Analysis of the Basalt (Micro-slide 24177).*

—	Per cent.	Molecular proportions.	—	Norm Per cent.
SiO ₂ . . .	48.36	0.806	Orthoclase . . .	7.23
TiO ₂ . . .	1.84	0.023	Albite . . .	22.01
Al ₂ O ₃ . . .	15.80	0.155	Anorthite . . .	27.80
Fe ₂ O ₃ . . .	0.42	0.003	Diopside	
Cr ₂ O ₃ . . .	0.05	..	CaO. SiO ₂ . . .	7.89
FeO . . .	6.54	0.090	MgO. SiO ₂ . . .	5.40
MnO . . .	0.15	0.002	FeO. SiO ₂ . . .	1.85
MgO . . .	10.03	0.251	Hypersthene—	
CaO . . .	9.96	0.178	MgO. SiO ₂ . . .	2.50
Na ₂ O . . .	2.61	0.042	FeO. SiO ₂ . . .	0.79
K ₂ O . . .	1.23	0.013	Olivine—	
H ₂ O+ . . .	1.42	0.078	2MgO. SiO ₂ . . .	12.04
H ₂ O— . . .	1.08	0.061	2FeO. SiO ₂ . . .	4.69
P ₂ O ₅ . . .	0.42	0.003	Magnetite . . .	0.70
CO ₂ . . .	Nil	..	Ilmenite . . .	3.50
S . . .	Nil	..	Apatite . . .	1.01
			Water . . .	2.50
TOTAL . . .	99.91	..	TOTAL . . .	99.91

SYMBOL (C. I. P. W.) III. 5. 4.
NAME :—Auvergnose.

The most notable feature of these analyses is the low values of potash, which reaches its maximum value of 1.23 per cent. in the basalt and in no other case reaches 0.5 per cent. The low value of 0.45 per cent. in the quartz-bearing rocks of the Salingyi complex, in which the silica value exceeds 75 per cent., is most remarkable, but as will be shown later there are strong reasons for believing that this is not a pure igneous rock. The same feature, the paucity of potash, is brought out by the microscopical examination of the rocks. In the holocrystalline rocks potash feldspars are entirely absent except in the pegmatite vein of the Salingyi complex, and this, judging from its surface outcrop, forms less than 0.01, probably less than 0.001 per cent. of the total volume of the igneous rocks of this complex. In the extrusive rocks, potash feldspars are not represented among the phenocrysts, even in the case of the acid varieties, the keratophyres, but may be present in the cryptocrystalline groundmass. There is a similar rarity of other potassic minerals such as the micas, and the rocks belong to a very definite Pacific suite, but even in such a suite such very low values of potash are remarkable. The igneous rocks of the Twindaung area to the north, in which potash reaches appreciably higher values, are also described by Professor Burri¹ as belonging fundamentally to a very characteristic Pacific group. With the exception of the rocks of the Kabwet area, the other Tertiary to Recent igneous rocks of Burma are also assigned by this author and by Dr. Chhibber² to Pacific suites, but unfortunately, as pointed out by Professor Burri, accurate mineralogical determinations and chemical analyses are in many cases lacking.

It is now proposed to conclude this portion of the paper by a discussion of the origin of two very characteristic but unusual rocks of the Salingyi complex, namely the quartz-oligoclase bearing-rocks which occur as lenticles in the gabbro, and the hornblende-granulite which occurs at the northern margin of this complex.

It will be recalled that the gabbros of the Salingyi complex contain irregular lenticular inclusions of quartz-oligoclase-bearing rocks, the petrological description of which is given on pages 165-170 (micro-slides 24185-7 and 24189-93) and an analysis of one of which is given as table 4. They consist essentially of quartz and basic

¹ C. Burri and H. Huber, *loc. cit.*, pp. 336-339.

² H. L. Chhibber, 'The Geology of Burma', London (1934), pp. 481-483.

oligoclase with subsidiary mafites, and in some instances (as in micro-slides 24193) as much as 20 per cent. epidote. With one exception (micro-slide 24188), the feldspars range in composition from 20 to 35 per cent. anorthite, in contrast to those of the gabbro itself which vary from 70 to 100 per cent. anorthite. The quartz occurs in large irregular grains up to two millimetres in diameter, surrounded by aggregates of smaller grains which occupy the interstices between the feldspars and are in some instances intimately associated with granulated feldspar at the shattered margins of the latter mineral. The optical orientation of the grains comprising

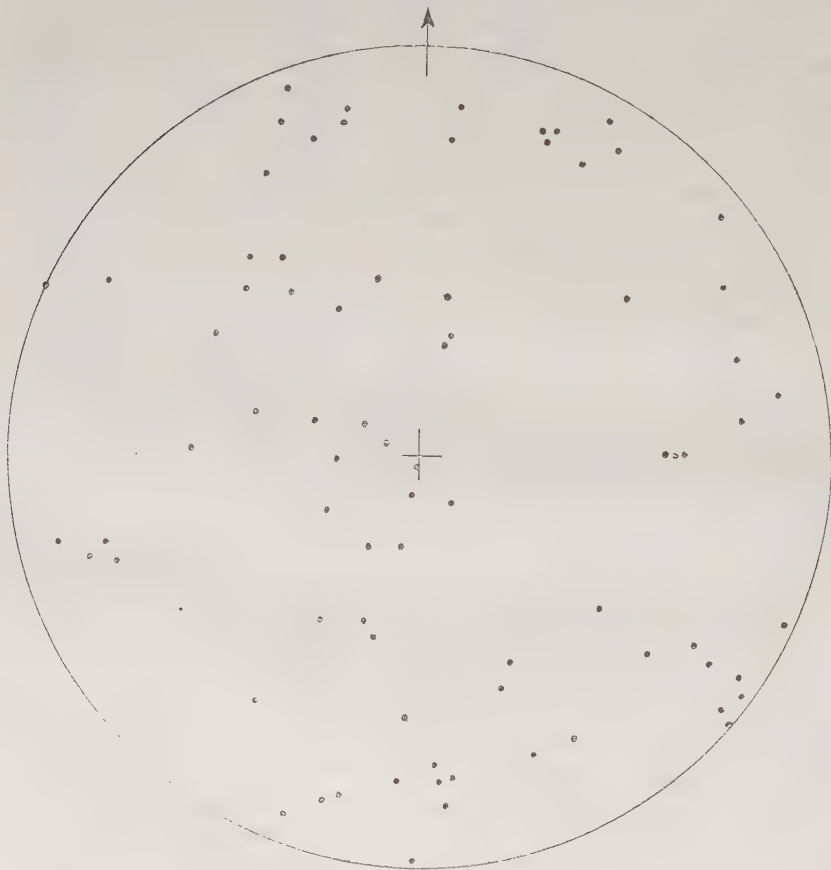


FIG. 3.—Projection showing the emergence of (ny) in 78 quartz grains in micro-slide 24190.

eleven distinct quartz aggregates in micro-slide 24190 was determined by means of the Fedoroff stage, and the results of this investigation are illustrated by text figures 3 to 6 in which the emergence of $n\gamma$ in the case of four aggregates, consisting respectively of 78, 65, 50 and 44 grains, representing 47 per cent. of the 502 determinations made, is shown. In the case of the first aggregate (text figure 3) there is no noticeable concentration of the poles, indicating that the optical orientation of the individual grains of which

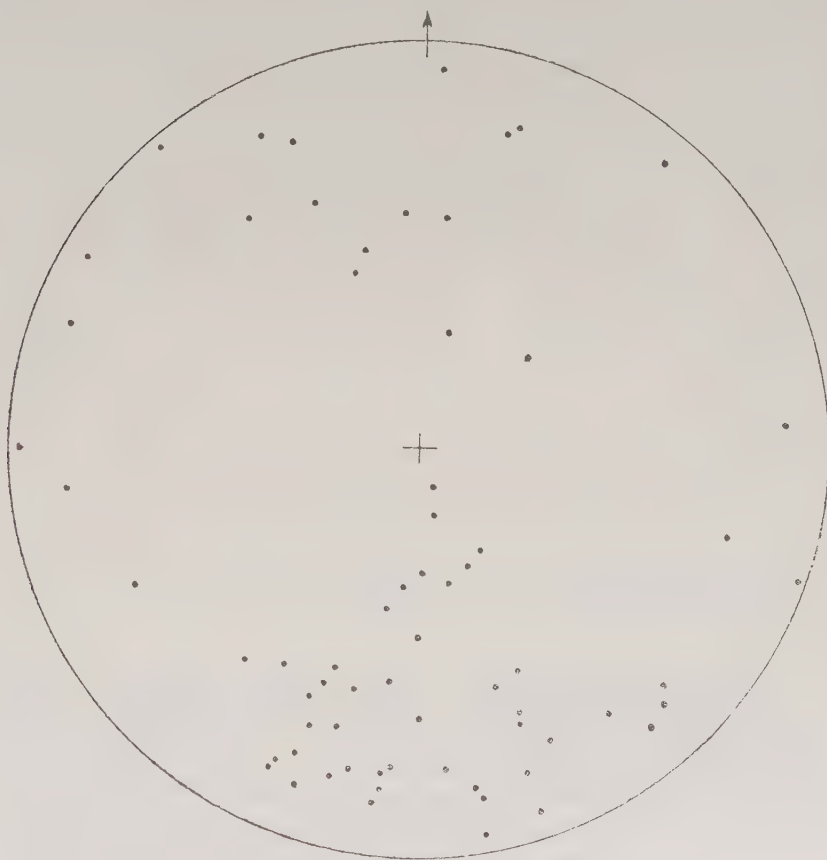


FIG. 4.—Projection showing the emergence of $(n\gamma)$ in 65 quartz grains in micro-slide 24190.

it is composed is promiscuous. In all the other aggregates investigated, illustrated by text figures 4, 5 and 6, selected as being typical of the remaining ten projections, there are varying degrees of concentration of the poles, indicating a similarity but no complete identity in the optical orientation of the various grains composing the aggregates.

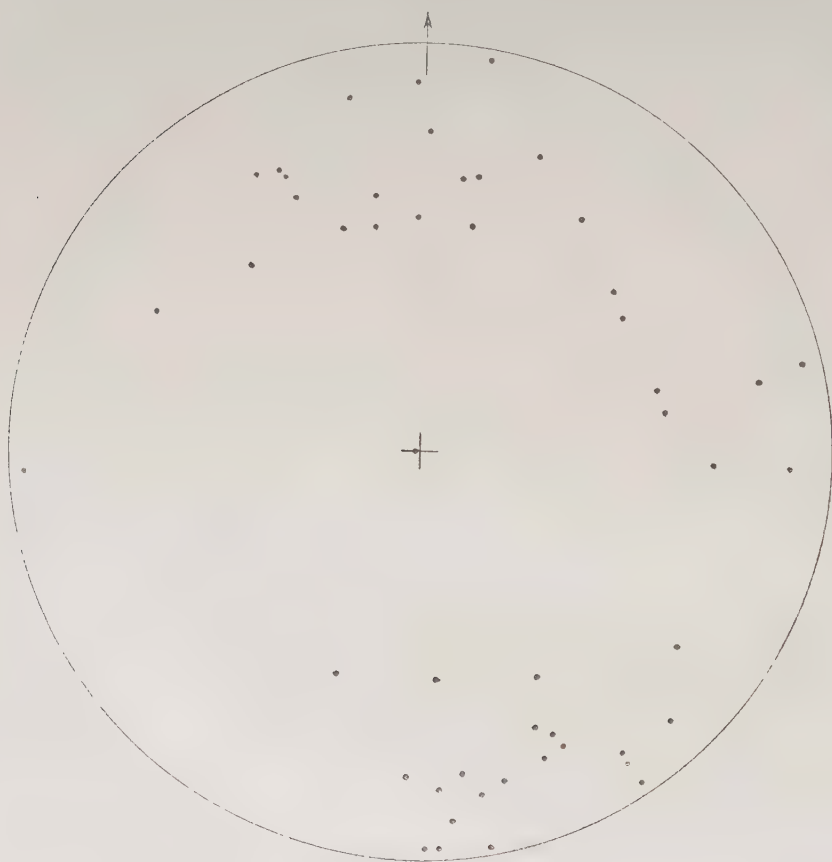


FIG. 5.—Projection of emergence of (nγ) in 50 quartz grains in micro-slide 24190.

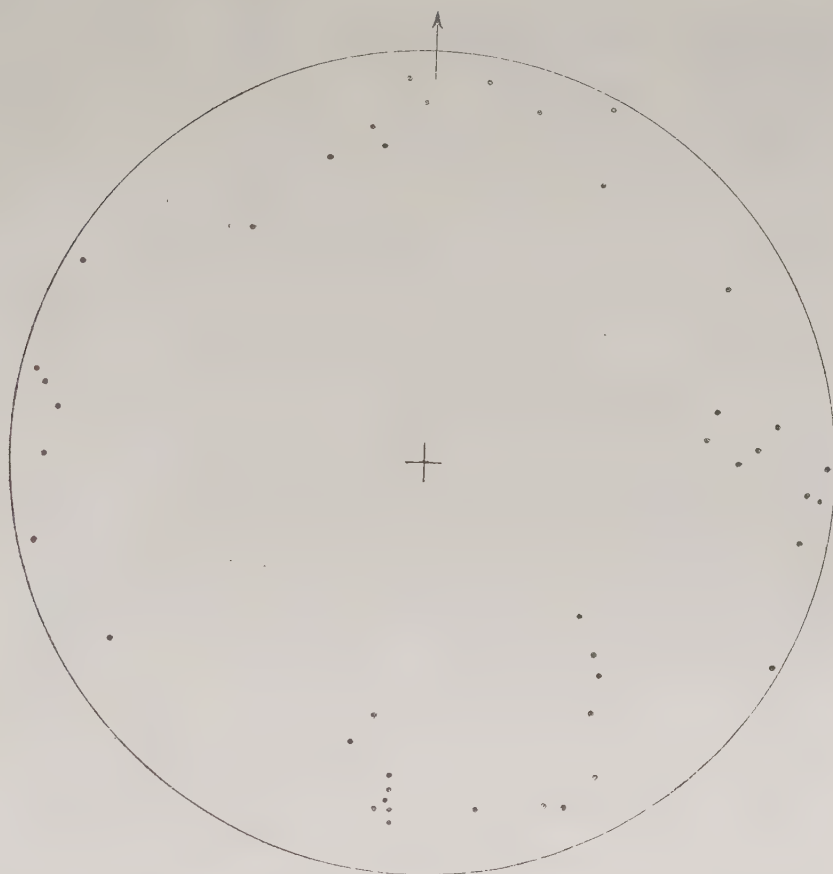


FIG. 6.—Projection showing the emergence of ($n\gamma$) in 44 quartz grains in micro-slide. 24190.

Other interesting features of these rocks are, the occurrence of deep-blue amphiboles of very small optic angle, exemplified in micro-slide 24198, and the intense marginal granulation of the feldspars. It will be recalled also, that where the contact with the gabbro is sharply defined, the feldspars of the latter rock are also intensely granulated, and the rock is characterised by veinlets and aggregates of epidote, sometimes with a core of allanite and associated with ilmenite and leucoxene. Finally, the chemical analysis of the quartz-oligoclase rock (*vide* table 4) shows many remarkable features the

most notable of which is the low value of 0.45 per cent. for the potash content in comparison with a silica content of 76.48 per cent. The C. I. P. W. classification¹ of this rock is I, 3, 4, 5, and in Washington's tables² only two representatives of this sub-range are given, one of which is stated to be a granite in contact with limestone.

The field occurrence of these rocks and their general mineralogical and structural characteristics, appear capable of either of two explanations; (a) that they are granophyric injections representing a late acid differentiate of the gabbroic magma, or (b) that they are produced by assimilation of arenaceous sediments incorporated in the still molten but viscous magma by overhead stoping.

The pronounced shattering shown by the gabbro in contact with the quartz-oligoclase rock, and the similar optical orientation shown by the quartz grains forming individual aggregates in the latter, are compatible with either hypothesis. Since the rock is devoid of schistosity, the latter phenomenon appears to be due to the granulation of large quartz grains, the 'ueberindividuen' of Professor Sander³. On the hypothesis of granophyric injection, this phenomenon may be interpreted as the result of the injection of viscous magma containing large quartz grains which had already crystallised, or, on the assimilation hypothesis, may be attributed to the fusion or solution of arenaceous sediments, followed by the crystallisation of large quartz grains from the silica-enriched magma, which, like the feldspars of the surrounding gabbro, were afterwards granulated by the continued rise of the viscous, almost solid, magma.

Support for the hypothesis of granophyric injection may possibly be seen in the intense clouding by inclusion seen in many of the feldspars of the gabbro (*vide* pages 161 and 164) an effect which is attributed by Mr. A. G. MacGregor⁴ to low grade thermal metamorphism, and which, in the case of the quartz-gabbros and eucrites of Ardnamurchan⁵ was, indeed, thought to have been brought about by the permeation of the rock mass by granophyric material.

¹ W. Cross, J. P. Iddings, L. V. Pirsson and H. S. Washington, 'Quantitative Classification of Igneous Rocks', London (1903).

² H. S. Washington, 'Chemical Analyses of Igneous Rocks', *U. S. Geol. Surv.*, Professional Paper 10, p. 107, (1917).

³ B. Sander, 'Gefügekunde der Gesteine', Vienna (1930), p. 179.

⁴ A. G. MacGregor, 'Clouded Feldspars and Thermal Metamorphism', *Min. Mag.*, XXII, pp. 524-538, (1931).

⁵ J. E. Richey and H. H. Thomas, 'The Geology of Ardnamurchan, north-west Mull and Coll.', *Mem. Geol. Surv. Scotland* (1930), pp. 267-268.

It is considered, however, that there are two very weighty objections to this hypothesis of granophyric injection: firstly, the chemical characteristics of the quartz-oligoclase rock, and particularly their extremely low potash content, and secondly, the occurrence in one instance of quartz-bearing rocks, otherwise similar to the quartz-oligoclase rock, in which the feldspars are identical with those of the gabbro itself. I am strongly inclined, therefore, to favour the hypothesis of assimilation of arenaceous sediments, which appears to be supported by the occurrence in the quartz-oligoclase rock of deep-blue amphiboles, related to hastingsite, similar amphiboles having been described by H. von Eckermann¹ as contact minerals developed in the Tennberg granite towards its contact with limestones. On this hypothesis also, the occurrence of albite-rich feldspars in the hybrid-rock finds a ready explanation, and may be attributed to the reaction of the gabbroic magma with the Pegu sediments in which sodium gives rise to a white powdery efflorescence on the surface of the Pegu outcrops and which Dr. Walker² found to contain 34.89 per cent. of Na_2O .

The rock which I have described as a hornblende-granulite (*vide* pages 171-173, micro-slides 24195-8) occurs at the northern margin of the Salingyi complex where it occupies an area of approximately one and a half square miles. Unfortunately, its contact with the gabbro was not observed owing to the rarity of exposures in this region, but its contact with the Pegu sediments to the north is characterised by the presence of hornfelsed sandstones (micro-slides 24199-201).

In the field, the hornblende-granulite is locally much shattered but in the hand specimen it is a fine-grained compact granulitic rock of black colour which is traversed by a small veinlet of slightly coarser material of similar texture. Microscopically, the salient features are an equigranular mosaic of green hornblende and andesine, which, particularly under high magnification, gives a strong impression of hornfels structure. In addition to the normal feldspars of the rock, the composition of which lies between 45 and 50 per cent. anorthite, the rock contains a number of larger crystals

¹ H. von Eckermann, 'The Rocks and Contact Minerals of Tennberg', *Geol. Foren. Stockholm*, (1923), pp. 465-539.

² *Mem. Geol. Surv. Ind.*, XXVIII, Pt. 1, p. 47, (1898).

of feldspar characterised by a somewhat sericitised basic core (80 to 90 per cent. anorthite) surrounded by a clear margin of andesine.

Structurally, this rock bears a remarkable resemblance to the beerbachite of the Odenwald¹ which it was my good fortune to see in the field on a memorable excursion led by Professors M. Reinhard and G. Klemm in July, 1934. The micro-slides of this rock which I have examined differ from the hornblende-granulite principally in the species of mafite, which in the Odenwald rocks consists either of pyroxene, sometimes with subsidiary hornblende with poikilitic enclosures of feldspar, or of chlorite pseudomorphs. Mr. A. G. MacGregor² states, however, that many varieties of the Odenwald rock are essentially hornblende-feldspar rocks. In other respects, the Odenwald beerbachites and the Salingyi rock are very similar, even to the presence of large feldspars with clouded basic cores and clear albitised margins.

I have compared the hornblende-granulite also with beerbachites from P. della Contessa, Elba, collected by Professor M. Reinhard, from Huampani, 47 km. east of Lima, Rimac valley, Peru, collected by Professor A. Buxtorf, and from the Mount Sinaia-Gora region of the Urals, collected by Professor L. Duparc. The latter consist of two distinct types, one of which, described by Dr. A. Rittmann³, is somewhat schistose and consists of rhombic and monoclinic pyroxenes, anorthite and quartz. This rock does not bear any close resemblance to either the hornblende-granulite or to other beerbachites which I have examined, but the second slide from this collection, consisting of basic andesine, augite and hornblende does bear a strong structural and mineralogical resemblance to both the Odenwald beerbachite and the hornblende-granulite. In the case of the other rocks mentioned above, the structural resemblance to the hornblende-granulite is also very great, and the principal mineralogical differences are to be found in the species of mafite. In the case of the beerbachite from Peru, Dr. P. Bearth⁴ has determined the feldspars, the anorthite content of which lies between 40 and 50 per cent. Like the hornblende-granulite also, the rock

¹ C. Chelius, 'Das Granitmassiv des Melibocus und seine Ganggesteine', *Notizbl. des Vereins für Erdkunde und der Grossh. Geol. Landesanstalt zu Darmstadt*, IV, Folge, 13. Heft, pp. 1-13, (1892).

² A. G. Macgregor, 'Scottish Pyroxene-Granulite Hornfels and Odenwald Beerbachites' *Geol. Mag.*, LXVIII, pp. 506-521, (1931).

³ A. Rittmann, 'Étude Pétrographique sur une Série de Roches des Gîtes Platinifères de l'Oural'; Thesis No. 657, University of Geneva.

⁴ P. Bearth, personal communication.

contains, in addition to this normal type of feldspar, a few crystals with basic cores and albitised margins, but the clouding by sericitisation of the basic portions, seen in the hornblende-granulite, is not noticeable in this rock.

Professor A. Buxtorf¹ informs me that the Peru beerbachite occurs as numerous dykes which can be traced for great distances, intruded into grano-diorites. The Ural beerbachites were also referred to by Dr. Rittmann² as dyke rocks, but, as field evidence is not given, this is thought to have been due principally to their resemblance to the Odenwald beerbachite, which at that time was thought to be a dyke in the Frankenstein gabbro. I am informed by Professor M. Reinhard³ that the Elba beerbachites occur as nodules varying from two or three to eight inches in diameter in the serpentines of the ophiolites⁴ of this region. Their origin, therefore, is not directly traceable but Professor Reinhard is inclined to regard them as acid magmatic segregations in the serpentines. The Odenwald beerbachites were regarded by Chelius⁵ as dykes but recently Professor Klemm⁶ has shown that they are masses of older rocks caught up in and metamorphosed by the Frankenstein gabbro, and considers further that they are metamorphosed basic sediments. This latter conclusion has been criticised by Mr. A. G. MacGregor⁷ who, as a result of their comparison with Scottish pyroxene-granulites and a critical review of the Odenwald evidence, regards them as metamorphosed igneous rocks. This conclusion rests partly on chemical grounds and MacGregor quotes the criteria of Bastin⁸ in support of his views. On the authority of Grubenmann⁹, however, Bastin states that chemical analyses are inadequate in some instances to distinguish between metamorphosed sediments and igneous rocks, since arkoses, shaly

¹ A. Buxtorf, personal communication.

² A. Rittmann, *loc. cit.*, pp. 33-34.

³ M. Reinhard, personal communication.

⁴ 'Ophiolite' is a term used by continental geologists to denote the association of serpentines, diabase, spilites and other basic rocks, frequently associated with deep sea sediments, which are of common occurrence in nappe structures, for which the term 'greenstone' is sometimes employed by English and American geologists.

⁵ C. Chelius, *loc. cit.*

⁶ G. Klemm, 'Petrographische Mitteilungen aus dem Odenwald', *Notizblatt des Vereins für Erdkunde und der Hessischen Geol. Landesanstalt zu Darmstadt*, V. Folge, 9. Heft, pp. 104-117, (1926).

⁷ A. G. MacGregor, *loc. cit.*

⁸ E. S. Bastin, 'Chemical Composition as a Criterion in identifying Metamorphosed Sediments', *Journ. Geol.*, XVII, pp. 445-472, (1909).

⁹ U. Grubenmann, 'Die krystallinen Schiefer', Vol. I, Berlin (1904), p. 12.

sand-stones and sandy shales approach igneous rocks very closely in composition. Whatever one's final views as to the sedimentary origin of the Odenwald beerbachites, the evidence adduced by MacGregor¹ in support of an igneous origin of the very similar Scottish pyroxene-granulites appears incontrovertible.

From the above summaries it appears that beerbachites, and rocks of great structural and mineralogical affinities to them, have widely varying genetic histories. In Peru, they are certainly dyke rocks; in Scotland metamorphosed igneous rocks; in the Odenwald, either metamorphosed igneous rocks or metamorphosed sediments, and in Elba, apparently neither of these, but magmatic segregations in the serpentines. Comparison with these rocks, therefore, does not bring us to any positive conclusion as to the origin of the hornblende-granulite of the Salingyi complex. The appeal to chemical evidence is also inconclusive. The analysis of this rock is given as table 3 (page 207). The calculation of the norm reveals no abnormal features and the alumina content is not in excess of that required to satisfy the available CaO, K₂O and Na₂O, neither is it abnormally rich in magnesia, potash, silica or iron, the predominance of either of which might, according to Bastin², point to a sedimentary origin. The position of this rock in the C. I. P. W. classification is III, 5, 4, 5, and in Washington's³ tables over a hundred representatives of this sub-range are given and include gabbros, diorites, dolerites, diabases, amphibolites, epidiorites, basalts, beerbachites, malchites and odinites. On chemical grounds, therefore, there is no reason for discarding the hypothesis that the hornblende-granulite may be an igneous rock. On the other hand, it may equally well be a metamorphosed sediment, as the Pegu sediments of this region are precisely those which Grubenmann⁴ states approach very closely in composition to igneous rocks. In attempting to solve the problem of its origin, therefore, we are driven back to field evidence and the micro-structural characteristics of the rock.

As stated above (page 159), the field evidence is inadequate as the basis of a final conclusion except that the form of the outcrop is incompatible with the dyke hypothesis. The rock may, eventually, be regarded as intrusive, but in this case its pronounced

¹ A. G. MacGregor, *loc. cit.*

² E. S. Bastin, *loc. cit.*, pp. 446-449.

³ H. S. Washington, *loc. cit.*, pp. 639-667.

⁴ U. Grubenmann, *loc. cit.*

hornfels texture suggests that it must have been metamorphosed by the gabbro, and so we are again confronted by the same problem as in the case of the Odenwald beerbachite, namely the choice between the hypotheses of a metamorphosed sediment or a metamorphosed igneous rock. It appears to me that, if they can be correctly interpreted, the key to the problem may be found in the large feldspar crystals with clouded basic cores and clear albitised margins, which occur both in the Odenwald rock and in the hornblende-granulite. Mr. MacGregor¹ regards these in the Odenwald rock as original zoned phenocrysts and in a previous paper² states:—

‘In the intermediate and inner zones of contact-aureoles thermal metamorphism has often, but not invariably, produced in the fresh plagioclase feldspars of lavas and minor intrusions a peculiar and easily recognisable type of clouding due to the development of minute inclusions. When, in the highest grades of such contact metamorphism, original plagioclase crystals have been recrystallised, the newly formed feldspar is unclouded. Clouded phenocrysts have, however, often remained stable although the feldspar of the finer-grained groundmass is completely granulitised by recrystallisation. This is because under contact-metamorphic conditions, large fresh crystals are more stable than small crystals.

The minute inclusions are very often restricted to the more basic portions of plagioclase crystals, and are absent from the more albite-rich parts. This fact suggests that the original nature of the feldspar controls the formation of inclusions.’

In the case of the hornblende-granulite of the Salingyi complex, the clouding of the central basic portions of the large feldspars is not the clouding by inclusion seen in many of the feldspars of the gabbro, but clouding by alteration. Also, I do not believe that the albitised margins have any connection with original zoning. Their composition is identical with that of the normal feldspars forming the bulk of the feldspar content of the rock, and in the many examples of zoned feldspars which I have studied I have seen no analogy to this abrupt change from a core of anorthite to a margin of andesine. The greatest range of composition seen in the zoned phenocrysts of the andesites was from 80 to 50 per cent. anorthite, and this was effected in several stages, whereas the large feldspars of the hornblende granulite show an abrupt change from 80 to 45 per cent. anorthite without zones of intermediate composition and without the least sign of zoning in either the basic core or the more acid margin. I believe, therefore, that the more acid margins represent either the albitisation of original feldspars of the composition

¹ A. G. MacGregor, *loc. cit.*

² A. G. MacGregor, ‘Clouded Feldspars and Thermal Metamorphism’, *Min. Mag.*, XXII, pp. 524-538, (1931).

of anorthite, or the secondary accretion of andesine to original feldspars of this composition. Furthermore, like Professor Klemm¹ in the case of the Odenwald beerbachite, I am inclined to regard these large feldspars not as relict phenocrysts but as crystals derived from the gabbro which have undergone marginal albitisation by reaction with a more acid rock which has been partly assimilated and highly metamorphosed by it. I would suggest, therefore, that the problem may be reduced to two possibilities, either that the hornblende-granulite is a highly metamorphosed representative of the keratophyres which outcrop at the western margin of the Salingyi complex, or that it is composed of highly metamorphosed sediments caught up in and partially mixed with gabbroic magma. I have previously mentioned the epidotisation and structural changes which are seen in the keratophyres towards their contact with the gabbro, and which I believe to be a hydro-thermal or low grade thermal metamorphism by the gabbro (it might possibly be a late hydro-thermal autometamorphism by the keratophyre magma itself, but it appears very doubtful whether this magma was sufficiently rich in calcium to produce the epidotisation). If the hornblende-granulite is a metamorphosed keratophyre the metamorphism which has produced it is of a totally higher order of intensity than that seen towards the eastern margin of the still recognisable keratophyres, and is probably due to keratophyres, or their hypabyssal equivalents, becoming involved in the gabbro magma at considerable depth. I would, however, emphasise that I consider a sedimentary origin of the hornblende-granulite to be by no means excluded.

¹ G. Klemm, personal communication to Mr. A. G. MacGregor, *vide* A. G. MacGregor, *Geol. Mag.*, LXVIII, p. 511, (1931).

CHAPTER VIII.

THE DETERMINATION OF THE FELSPARS BY THE FEDOROFF METHOD.

The determinations were carried out with the latest model of the Universal stage by the firm of Leitz, mounted on a Leitz microscope (Stativ CM) which was fitted with a special condenser designed for use with the Fedoroff stage. Special objectives U. M. 1, 2, 3 and 4 were employed and, in general, it was found that the smallest magnification, compatible with the size of the crystal under investigation, was the most satisfactory for the orientation of optical vectors. In determining the optical symmetry elements, therefore, objective U. M. 4 was employed only in connection with small microlites and small zones of zoned phenocrysts. For the orientation of morphological directions, on the contrary, the greatest obtainable magnification was found to be advantageous and for this purpose objectives U. M. 3 and U. M. 4 were employed. In the majority of cases, ocular 3 was used both for the orientation of optical vectors and morphological directions, but in the case of very small lamellæ or zones, periplan-ocular 8 was employed. The majority of the thin sections were more than standard thickness, several being as much as 0.06 mm. thick. This also was found to be advantageous for the orientation of morphological directions.

The stereographic projections obtained by measurement were interpreted by means of Professor M. Reinhard's¹ determinative stereograms, *viz.* :—

PLATE I.—Projection perpendicular to [001], showing the migration of optical vectors with reference to fixed crystallographic directions.

PLATE II.—Projection perpendicular to $n\beta$, showing the migration of crystallographic poles with reference to fixed optical symmetry elements.

PLATE III.—Projection on (010) showing the migration of optical vectors with reference to fixed crystallographic directions.

PLATE IV.—Projection on (001) showing the migration of optical vectors with reference to fixed crystallographic directions.

¹ M. Reinhard, 'Universal Drehtischmethoden', Basel, (1931), pp. 1-119.

PLATE V.—Projection perpendicular to $n\beta$, showing the migration of crystallographic directions (twinning axes) with reference to fixed optical symmetry elements.

Certain curves of Plates II and V have been modified by Dr. F. Spaenhauer¹, and in these instances the revised Spaenhauer curves have been employed.

For the determination of the anorthite value Plate II was employed, and this plate, with the Spaenhauer modifications, is reproduced as Plate 30 of this paper, to enable the reader to ascertain the distribution in the complete determinative stereogram of the individual curves which are reproduced in the following text figures.

For the determination of the twinning law in cases of parallel and complex twinning, Plates III and IV were employed for twinning on (010) and (001), respectively, and in cases where the pole of the twin axis was obtained by the constructional method of Nikitin², Plate V was employed.

Plate I of the determinative stereograms was used principally for the determination of morphological directions, such as the poles of zoning faces, for which curves are not given in the determinative stereograms. For this purpose the required orientation was given to the stereographic projection obtained by measurement, by rotating the pole of (010) to the intersection of the equatorial diameter and the fundamental circle, and the subsequent rotation of the projection about the equatorial diameter until the poles of the optical symmetry elements coincided with their respective curves. The co-ordinates ϕ and ρ of the pole under investigation were then obtained with the aid of a Wulff's net, and the face determined by reference to Goldschmidt's³ tables.

As a check on the determinations, and to avoid ambiguity in interpretation, specimens were selected which showed two or more determinable morphological directions. When only one morphological direction is determinable it is possible in some instances to interpret the resulting pro-

¹ F. Spaenhauer, 'Ueber das Ergebnis von Messungen an synthetischen Plagioklasen mit Hilfe des Universaldrehtisches', *Schweiz. Min. Petr. Mitt.*, XIII, pp. 356-365, (1933).

² W. W. Nikitin, 'Korrekturen und Vervollständigungen der Diagramme zur Bestimmung der Feldspate nach Fedorows Methode', *Min. Petr. Mitt.*, Bd. 44, (1933).

³ V. Goldschmidt, 'Krystallographische Winkeltabellen', Berlin (1897), pp. 139-142.

jection in more than one position on Plate II. With basic feldspars, a pole falling at 90 per cent. on the (010) curve can also be interpreted on the (001) curve, on which it will fall between the graduations representing 70 and 80 per cent. anorthite. If only one pole is obtained the interpretation is therefore ambiguous. If, however, two morphological poles are measured the ambiguity is removed since in the basic range there is only one position in which the two poles will coincide with or approximate to the curves and at the same time indicate the same composition. Similarly in the acid range, the same pole can be interpreted in two different positions on the (010) curve; either in the left hand quadrant, between 20 and 30 per cent. anorthite, or in the right hand quadrant, between 0 and 20 per cent. anorthite. Here again the ambiguity is removed if two morphological directions are determinable. Since the determination of the anorthite value is the most important object of the investigation, the advantages accruing from the selection of specimens showing two morphological directions, are sufficient to outweigh the resultant vitiation of statistical analyses of the incidence of twinning laws. Where cleavage is not developed, the desirability of determining two morphological directions results in the selection of specimens showing two systems of twinning, and this undoubtedly results in an exaggerated estimate of the importance of pericline twinning since this form of twinning was rarely observed except in combination with other twinning laws. Similarly, the importance of twinning on (010) is minimised since twinning on this face is most common, not only in combination with other laws, but also in specimens showing only one system of twinning. Since, however, the selection will have the same tendency to exaggerate the importance of pericline twinning and to minimise the importance of twinning on (010) wherever it is applied, it is not suggested that it entirely deprives statistical analyses of the incidence of twinning laws of their possible value. Their ultimate value probably lies in the fact that certain laws may be found to be characteristic of feldspars of certain compositions, or to be connected with certain physical conditions either of crystallisation or of the rocks' subsequent history. Our present knowledge is inadequate to form the basis of any reliable conclusion on these points, but since it is only by the accumulation of evidence that these questions will become partially or completely soluble, the statistics are not without interest and importance.

TABLE 6.—Statistical analysis of the morphological directions determined in the felspars.

Rock.	Anorthite value.	No. of Felspars determined.	TWINNING LAWS.										CLEAVAGE.			ZONING.									
			NORMAL.				PARALLEL.				COMPLEX.		(001).	(010).	(110).	(001).	(111).	(110).	(101).						
			Manebach.		Baveno right.	Baveno left.	Carlsbad.	Acline.	Perthine.	Ala.	Albite-Ala.	Albite-Carlsbad.								Manebach-Ala.	Manebach-Acline.				
			Albite.	8																					
		No. of Twinning Laws determined.	15	11	1	3	5	7	53	8	3	13	2	1	111	16	1	6	5	3	3	2	1		
			6	15	8	1	3	9	49	8	3	13	2	1	111	16	1	6	5	3	3	2	1		
	85-100		15	11	1	3	5	7	53	8	3	13	2	1	111	16	1	6	5	3	3	2	1		
	70-90		17	36	1	3	9	49	53	8	3	13	2	1	111	16	1	6	5	3	3	2	1		
	45; 80		15	23	13	1	3	9	49	8	3	13	2	1	111	16	1	6	5	3	3	2	1		
	Hornblende-granulite		45; 80	15	23	13	1	3	9	49	8	3	13	2	1	111	16	1	6	5	3	3	2	1	
	Hybrid rocks		20-85	16	29	12	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
	Hybrid rock		75-95	5	10	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
	Hornfels		25-80	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
	Micro-hornblende-gabbro.		80-90	10	15	8	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
	Diabase		35-40	4	9	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
	Andesite (Maukthayet).		40-80	27	48	23	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
	Andesite (Shinnakaung)		45-80	14	24	12	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
	Variolite		30-40	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
	Tuffs		35-60	15	16	9	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
	Keratophyre		5-10	9	17	5	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
	Quartz-keratophyre		5-10	11	18	9	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
	Basalts		75-95	21	25	13	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
	TOTAL		..	180	295	136	15	4	49	7	53	8	3	13	2	1	111	16	1	6	5	3	3	2	1

Total Twinning Laws.			Summary.		Idem percentage.	
Normal	.	159				54
Parallel	.	117				40
Complex	.	19				6
Total	.	295				
Twins on (010)	.	201				68
Perthite Twins	.	53				18
Twins on (001)	.	33				11
Baveno Twins	.	8				3
Total	.	295				

Idem percentage.

Summary.

Total Twinning Laws.

Normal	..	159
Parallel	..	117
Complex	..	19
Total	..	295
Twins on (010)	..	201
Perthine Twins	..	53
Twins on (001)	..	33
Baveno Twins	..	8
Total	..	295

A total of 180 feldspars, ranging in composition from 5 to 100 per cent. anorthite, and including examples of every known twinning law, have been determined by the Fedoroff method. The wealth and variety of the twinning laws is shown by table 6 in which a statistical analysis of the 441 morphological directions determined is given. In compiling this table, duplication of twinning laws and of cleavage or zoning directions, in respect of the same specimen has been avoided. In the feldspar figured in text figure 7, for instance, there are two systems of albite twinning (1-2 and 3-4) and two of ala twinning (1-3 and 2-4) while cleavage on (001) occurs in all four

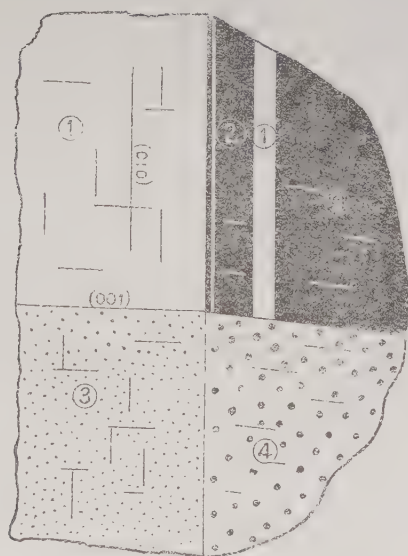


FIG. 7.—Illustrating an example of albite and ala twinning.

1—2 } Albite law.
 3—4 }
 1—3 } Ala law.
 2—4 }

individuals and on (010) in two of them. In this and similar cases, however, albite and ala twinning and cleavage on (001) and (010) have each been entered only once in the table in respect of any one feldspar.

Twinning according to complex laws has been recognised only when two lamellæ in the relationship required by the complex law

The authenticity of complex laws. appear to be actually in contact. Frequently when interpretation by means of Plates

III and IV of the determinative stereograms, or by the construction of the twinning axis indicates that two lamellæ are in the complex relationship, examination under high powers reveals the presence of a very narrow lamella of undeterminable orientation between them. Such cases have been interpreted as examples of combined normal and parallel twinning and only when examination under the highest available magnification fails to reveal the presence of an intervening lamella has the existence of complex twinning been postulated. The absence of a detectable lamella of other orientation between two lamellæ in the complex relationship is not absolute proof of the realisation of the complex law. Professor M. Reinhard¹ has pointed out that even where no intervening lamella is detectable, it is still possible that the two lamellæ in the complex relationship are separated by many lattice planes of other optical orientation, but, since the microscopist deals only with phenomena which are observable by optical means, his results can be interpreted only by postulating the existence of complex twinning laws.

In the case of twinning on (001), parallel and complex laws are not *a priori* distinguishable. For acid oligoclase the angle γ is 90°, and since the two crystallographic axes

Complex twinning on (001). [100] and [010] are perpendicular to one another, [100] the axis of ala twinning is identical with $\perp$ [010] the axis of complex manebach-acline twinning.

Similarly, [010] the axis of acine twinning is identical with $\perp$ [100] the axis of complex manebach-ala twinning. In the case of feldspars of other compositions the angle γ differs from 90° but the deviation from 90° is so small that parallel and complex laws are still indistinguishable by optical means. For this reason, cases of non-normal twinning on (001) have been interpreted as parallel

¹ M. Reinhard, *op. cit.*, p. 85.

twinning except where lamellæ of three different orientations occur in contact with one another. In such cases, as for example in the felspar depicted in text figure 8 it is considered more logical to interpret them as examples of normal, parallel and complex twinning, rather than as examples of normal and two different parallel laws.

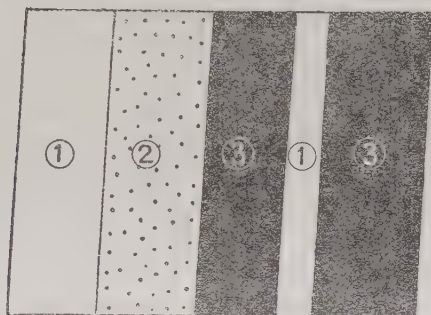


FIG. 8.—Illustrating an example of complex twinning on (001).

1—3 acline law=complex manebach-ala.

2—3 manebach law.

1—3 complex manebach-acline law=ala law.

In this example (figure 8) individuals 2 and 3 are in the normal relationship, and 1 and 2 in the position required by the acline (equals manebach-ala) law. The relationship of 1-3 has therefore been regarded as an example of the complex manebach-acline (equals ala) law. Whether in this instance the relationship of individuals 1 and 2 is described as acline or as manebach-ala is immaterial, but if it is described as acline then the relationship of 3 to 1 should be described as manebach-acline; conversely, if the relationship of 1 to 2 is described as manebach-ala, that of 3 to 1 should be described as ala.

The summarised statement in table 6 shows that normal twinning laws slightly preponderate, the 159 examples recorded representing 54 per cent. of the total twinning laws determined. Parallel twinning with 117 examples is responsible for 40 per cent. of the total laws determined, and the 19 examples of complex twinning for only 6 per cent. of the total.

Relative frequency of the twinning laws.

In the feldspars determined, (010) is the most prevalent association plane, twinning on this face forming 68 per cent. of the total twins determined. The pericline composition plane with 18 per cent. of the total is next in frequency, (001) with 11 per cent. of the total, third, and baveno twinning [twinning on (021) and (021)], forming only 3 per cent. of the total twinning laws, is very rare.

Relative frequency of various faces as association planes.

The following remarks on the incidence of the various twinning laws in the rocks investigated are intended merely to draw attention to salient features of their distribution in these rocks. It is not suggested that the number of examples determined is adequate to form the basis of broad generalisations as to the incidence of twinning laws, but some discussion of the question is pertinent since it is only by the accumulation of such evidence that broad generalisations as to the chemical and physical conditions which influence twinning may become possible.

The albite law, with a total of 136 examples, is not only the most frequent law but is also the most uniformly distributed throughout the various rock types. Its ubiquity is also largely responsible for the high percentages of normal twinning and of twinning on (010). It frequently occurs in combination with parallel and complex twinning on (010) and with pericline twinning.

The Albite law.

The pericline law, with 53 examples, is next in numerical importance to the albite law, but with 43 of the examples occurring in intrusive rocks it appears to show a marked predilection for these rocks. The occurrence of only two examples in 41 feldspars determined in andesitic rocks, or including the andesitic tufts, in 56 such rocks, is remarkable. It occurs most frequently as fine polysynthetic twinning in combination with twinning on (010) and not infrequently accompanies twinning on (001). Only one example of simple pericline twinning was observed.

The Pericline law.

Next in numerical importance is the carlsbad law with 49 examples. This law, in contrast to the other numerically important parallel law (pericline), finds its maximum

The Carlsbad law. representation in the extrusive rocks and notably in the andesites, in which 41 feldspars showed 19 examples of carlsbad twinning, occurring usually in combination with albite and in some instances with complex albite-carlsbad twinning.

Of twinning on (001), manebach, with 15 examples all of polysynthetic twinning was the most prevalent law. The most noticeable feature of its distribution is the occur-

The Manebach law. rence of six examples in 17 feldspars determined in the gabbros. It occurred most frequently in combination with twinning on (010) and frequently also with pericline twinning.

Of the eight examples of the ala law, six occurred in extrusive rocks and four of these in the acid varieties, the keratophyres. The same tendency is observable in the case of the

The Ala and Acline laws. acline law of which the seven examples determined were restricted to the extrusive rocks.

The eight examples of the baveno laws (four each of baveno right and baveno left) occurred in feldspars with an anorthite value of 50 per cent. or more, and four of them in

The Baveno laws. feldspars with an anorthite value of over 75 per cent. The occurrence of two examples of *polysynthetic* baveno twinning, both in combination with twinning on (010) and (001) is worthy of mention.

Of the complex laws, albite-carlsbad accounts for two-thirds of the total of 19 examples. Like the carlsbad law, it finds its

The Albite-Carlsbad law. maximum development in the andesites in which seven of the 13 examples occur.

Of the remaining complex laws the numbers determined (albite-ala, 3; manebach-ala, 2 and manebach-acline, 1) are insufficient

Other complex laws. to warrant even the most tentative generalisations regarding their distribution.

The most frequent direction of cleavage was (001), 62 per cent. of the feldspars determined showing cleavage on this face. Cleav-

Cleavage. age on (010) was recognised in 16 examples, or eight per cent. of the feldspars determined.

Cleavage on (1 $\bar{1}$ 0) was determined in one individual. The only rock in which no cleavage was recognisable in the feldspars is the

variolite, in which the feldspars occur in the form of skeleton crystals with exaggerated elongation after (010), with the result that the lamellæ are possibly too narrow to permit the recognition of cleavage on (001).

Comparison of the poles obtained by measurement with the curves of the determinative stereograms.

The distribution in the determinative stereograms (Plates II and V of Professor Reinhard's determinative stereograms) of the poles obtained by measurement is shown by text figures 9, 10 and 11, and Plate 31 of this paper. In text figures 9, 10 and 11 the appropriate curves from Professor Reinhard's Plate II (Plate 30 of this paper) have been reproduced without reference to their position in the stereogram, which, however, may be ascertained by reference to Plate 30 of this paper. In the following plate, the poles of the twinning axes determined, are superimposed on a reproduction of Plate V of Professor Reinhard's stereograms.

In order to avoid duplication of text figures, the poles have been classified into three groups. In each of the text figures 9, 10 and 11, curve A and its associated poles represent the distribution of the poles of feldspars determined in the intrusive rocks of the Salingyi complex, together with their associated hybrid and contact rocks, and also in the micro-hornblende-gabbro, that is to say of the rocks given in horizontal columns 1-7 of table 6. In these curves three groups of poles are distinguishable; those lying between 20 and 40 per cent. anorthite pertain to the acid hybrid rocks and to the hornfels, those lying between 40 and 60 per cent. anorthite to the hornblende granulite, and the remainder to the olivine gabbro, gabbro, micro-hornblende-gabbro and basic hybrid rock, with a few poles from the basic portions of the albitised basic feldspars occurring in the hornblende granulite (*vide* page 172 *supra*). Owing to the congestion of poles at the basic ends of the curve it has been impracticable to segregate these poles from those of the gabbros.

Curve B and its associated poles in each of the three text figures represents the poles of feldspars determined in the andesites, and their associated tuffs, and in the diabase and variolite, that is to say in the rocks occurring in columns 8-12 of table (6). In these curves it has not been practicable to segregate the poles of the various rocks but mention should be made of the fact that the wide

Explanation of figures 9, 10 and 11.



FIG. 9.—Showing the position of the poles of composition planes (010) with reference to the determinative curves.



FIG. 10.—Showing the position of the poles of composition planes (001) and the pericline composition plane with reference to the determinative curves.



FIG. 11.—Showing the position of the poles of cleavage on (001) with reference to the determinative curve.

range of composition, reflected in the elongated field of the poles, shown in these curves is due to zoning. These rocks contain no feldspars the average composition of which is either as basic as the poles lying at the anorthite end of the curve would indicate or, with the exception of the variolite, as acid as the poles lying at the acid end of the curve would suggest. The extremes at both ends of the curves represent the most basic and the most acid zones in the feldspars determined.

Curve C of each of the three figures pertains to the keratophyres and the basalts, *i.e.*, the rocks occurring in columns 13-15 of table 6. The poles of the keratophyres occurring at the acid end of the curve, are readily distinguishable from those of the basalts which lie between 70 and 100 per cent. anorthite.

In Plate 31 the three groups of twinning axes, distinguished by characteristic signs, correspond to the three groups distinguished in curves *a*, *b* and *c* of the text figures, except in the case of the last group in which the basalts are not represented. No twinning axes were determined in these rocks as in most cases the feldspars were so small that only the largest lamella was determinable, and the twinning laws were established by the extinction relationships of the lamellæ.

The Dispersion of the Points.

A conspicuous feature of text figures 9 to 11, and indeed of all such published diagrams, showing the relationship of the poles obtained by measurement to the standard curves depicting the migration of morphological directions with reference to fixed optical symmetry elements, is the pronounced scattering of the points. Poles lie not only on the curves but also on either side of them and, in fact, occupy a belt, varying in different instances, and in different positions along the length of the same curve, from three to eight millimetres in width. These belts contain, but are not symmetrically disposed to, the curves. Possible explanations of this phenomenon are:—

- (a) That the discrepancies are due to inaccurate measurements, arising either from faulty observation or from the use of inaccurate instruments.
- (b) That the standard curves themselves are incorrect.

- (c) That the directions determined are not true crystallographic directions but vicinal directions.
- (d) That the orientation of the indicatrix in the crystal is dependent not only on the anorthite value, but is influenced also by some other chemical component, as for example, potash.
- (e) That small variations in the position of the indicatrix are produced by factors other than chemical composition.

Finally, it is possible that in individual cases two or more of these factors may have operated to produce the observed deviation.

The first four of these hypotheses have been considered by previous observers, whose conclusions on one or more aspects of the subject are scattered throughout the somewhat voluminous literature on the Fedoroff method. Without the assistance of Prof. M. Reinhard, an important reference to the subject would have escaped the author's attention, and since other investigators, without this advantage, are liable to suffer a similar handicap, it appears that the whole problem may be profitably reviewed in a single paper. This the author has endeavoured to do in the following paragraphs, in which the results of his own experience are incorporated.

The first possibility has been considered by G. Manolescu¹ and Dr. F. Spaenhauer², who, as a result of repeated measurements of the same material by means of several

The inaccuracies of measurement.

different instruments and by different observers, have shown that discrepancies arising from these causes are much too small to account for the observed dispersion of the points. This conclusion was based on a study of the distribution of the poles of composition and twin planes. A similar but slightly less pronounced dispersion of the poles of cleavage is observable in text figure 11. The question of the dispersion of cleavage poles was not considered by Spaenhauer as the synthetic feldspars studied by him showed no trace of cleavage. It has been the author's experience that, owing to its restricted length, the co-ordinates of cleavage are more difficult to establish than those of composition planes, which frequently transverse the whole length of the

¹ G. Manolescu, 'Ueber die Lage der morphologischen Bezugsrichtungen bei Plagioklasen und ihre Verwendbarkeit zur Bestimmung des Anorthitgehaltes', *Schweiz. Min. Petr. Mitt.*, XIV, pp. 452-463, (1934).

² F. Spaenhauer, 'Ueber das Ergebnis von Messungen an synthetischen Plagioklasen mit Hilfe des Universaldrehtisches', *Schweiz. Min. Petr. Mitt.*, pp. 356-365, (1933).

crystal and a corresponding decrease in the accuracy of the determination of cleavage poles may therefore be expected. In no case, however, in which the pole lay a considerable distance from the curve, have independent measurements yielded poles which lay more than $1\frac{1}{2}$ millimetres from those originally obtained. Such discrepancies would produce a field of scattering of not more than three millimetres in diameter, and since the actual field of dispersion is approximately twice as great, it is concluded that in the case of cleavage poles also, inaccuracies in measurement are insufficient to account for the phenomenon.

As regards the accuracy of the curves, Professor M. Reinhard¹ himself states 'Sie sind sicher alle nur annähernd richtig', and the

The inaccuracy of the curves. same remark applies to the revised curves of Spaenhauer², which are based on the same

fundamental data and which have been used for the present work. The deviation of any individual pole from the curve might therefore be attributed to the inaccuracy of the curve itself, but since the poles obtained by measurement lie on both sides of, and varying distances from, the curves, this hypothesis is clearly incapable of explaining the scattering, and it is quite impossible to draw any one curve through the poles obtained.

As a result of his classic work on vicinal faces, Sir H. A. Miers³ showed not only that the angles between corresponding faces on

Vicinal faces. crystals of the same substance are variable, but also that similar variations are observable between different pairs of corresponding faces of the same crystals. He showed also that the inclination of the faces varied during growth of the crystal, and concluded that 'the vicinal planes, though they vary in inclination, always belong to the well defined zones'. The same observer also drew attention to vicinal phenomena in twinning and refers to earlier works⁴ on proustite and bournonite in which it was shown that in the union of twin crystals 'the two individuals are not always in exactly the position demanded by the law of twinning but may deviate therefrom by several minutes or even a degree or more'.

¹ M. Reinhard., 'Universal Drehtischmethoden.' Basel, (1931), pp. 107-108.

² F. Spaenhauer., *loc. cit.*, pp. 357-358.

³ H. A. Miers, 'An Enquiry into the Variation of Angles observed in Crystals; especially of Potassium-alum and Ammonium-alum', *Phil. Trans. Roy. Soc. A*, Vol. CCII, pp. 459-523, (1904).

⁴ H. A. Miers, 'Mineralogical Magazine', Vol. VI, p. 77, (1884); *op. cit.*, VIII, p. 75.

Elsewhere ¹ Miers also states :—

‘The crystals of natural minerals, which grow, doubtless, under very variable conditions, constantly exhibit vicinal faces; these are very near to the faces of simple forms, and therefore possess very high indices. Their interest and importance consist in the fact that, whatever be their indices, the number of the facets corresponds to the symmetry of the crystal, and they are therefore most valuable aids in determining the class to which it belongs.’

This conclusion is confirmed by the more recent work of Professor G. Kalb, ² who in his latest contribution to the subject states :—

‘Unter Zugrundelegung der Vizinalerscheinungen als realer Oberflächenercheinungen der Kristalle lässt sich eine reale Kristallmorphologie entwickeln, die die von der klassischen Kristallmorphologie aufgestellten Grundgesetze der Kristallgeometrie nur als Grenzgesezte anzuerkennen vermag, die aber die wichtigsten Aufgaben des Kristallographen, nämlich die Bestimmung der Symmetrie und der Formenentwicklung für alle Kristallarten durchzuführen gestattet.’

Some of the earlier observations of Kalb are, however, at variance with Miers’ conclusion that vicinal faces ‘always belong to well defined zones’, and the following conclusions of this author are of sufficient importance to merit quotation *in extenso* :—

‘Von den Charaktereigentümlichkeiten der Vizinalflächen glaubte Schuster zwei angeben zu können, die von allen früheren Beobachtern mit gleicher Sicherheit erkannt seien. Er schrieb :—“Es wurde erkannt, dass die Vizinalflächen in Zonen liegen, welche durch die Umgrenzungskanten der Hauptflächen gehen, denen sie angehören, zugleich aber auch bezüglich der Lage innerhalb dieser Zonen auf den verschiedenen Flächen sich verschieden verhalten, indem sie auch hierin von dem Symmetriegrade der zugehörigen Hauptflächen beherrscht werden.” ³Wir können diesem Satze Schusters nur mit einer Einschränkung zustimmen, indem wir sagen, dass die Vizinalflächen den Zonen nahe liegen, welche durch die Umgrenzungskanten der Hauptflächen gehen, denen sie angehören, und ausserdem in der Zonenlage dem Symmetriegrade der zugehörigen Hauptflächen zustreben, ohne ihn immer zu erreichen. Dass Abweichungen der Vizinalflächen in der Zonenlage vom Symmetriegrade der Hauptflächen vorkommen können, hat Gaubert gezeigt. So beobachtete er auf einer rechtwinklig verzerrten Hexaederfläche eines Analcimkristalles von den Zyklo peninseln eine ikositetraedrische Vizinalpyramide, die über die Spitze verschiedene Winkel aufwies (0 26’ und 0 42’). In gleicher Weise können Vizinalbildungen eine höhere Symmetrie vortäuschen. So fand Gaubert auf (110) Flächen von Vesuvian, die fast quadratischen Umriss zeigten, eine vierseitige Vizinalpyramide, deren Winkel über die Spitze annähernd gleich waren (12’ und

¹ H. A. Miers, “Mineralogy”, Macmillan & Co., London, (1929), p. 109.

² G. Kalb, ‘Die Bedeutung der Vizinalerscheinungen für die Bestimmung der Symmetrie und Formenentwicklung der Kristallarten’, *Zeitschr. Krist.*, Bd. LXXXIX, pp. 400-409, (1934).

³ The italics are mine.

18'). Es zeigt sich hier deutlich die Abhängigkeit der Lage der Vizinalflächen von den äusseren Bildungsbedingungen der Kristalle'.¹

And :—

'Für die Vizinalflächen gilt im allgemeinen keines der drei Grundgesetze der Krystallogometrie :—

- (1) Die Vizinalflächen haben keine konstante Lage zu den Grundflächen ; sie zeigen Lageschwankungen, wenn auch nur innerhalb enger Grenzen, nicht nur von Krystall zu Krystall einer Krystallart, sondern selbst auf verschiedenen gleichwertigen Flächen desselben Krystalls.
- (2) Die Vizinalflächen gehorchen nicht dem Gesetz der einfachen rationalen Achsenabschnitte.
- (3) Selbst die für die Grundflächen angenommenen Gesetze der Symmetrie lassen sich nicht ohne weiteres auf die Vizinalflächen übertragen'.²

Since the inclination of vicinal faces varies in different instances, and even on the same crystal, the hypothesis, that composition planes are not true crystallographic but vicinal planes, is capable not only of explaining the deviation of any one individual pole from the curve, but also of explaining the scattering of the poles. In view of this conclusion it will now be considered whether phenomena observed during the determination of the feldspars, or the results obtained, afford any evidence that the scattering of the poles may be partially attributable to this cause.

The subject was studied by G. Manolescu³, who summarised the earlier references to irregularities in composition planes, and in addition to studying visible morphological irregularities, compared the positions of symmetry and composition planes of normal twins. In the case of normal twinning, the plane of composition should coincide with the twin plane or plane of symmetry between the two hemitropes. It follows, therefore, that if this condition is completely realised, the morphological plane of composition should itself be a plane of optical symmetry. This means that when the plane of composition is oriented perpendicular to the K axis⁴ of the universal stage, not only should the extinction of the two hemitropes

¹ G. Kalb, 'Typische vierseitige Vizinalpyramiden auf parallelkantigen viereckigen Grundflächen holöedrischer Kristalle', *Zeitschr. Krist.* Bd. LXXIII, Heft 2, pp. 266-269, (1930).

² G. Kalb, 'Bemerkungen über Vizinalerscheinungen', *Zeitschr. Krist.*, A. 86, pp. 1-7.

³ G. Manolescu, 'Ueber die Lage der morphologischen Bezugsrichtungen bei Plagioklassen und ihre Verwendbarkeit zur Bestimmung des Anorthitgehaltes.' *Schweiz. Min. Petr. Mitt.*, Bd. XIV, pp. 452-463, (1934).

⁴ The connotation of the axes of the universal stage employed in this paper is that given by Reinhard, 'Universal Drehtischmethoden', Basel, (1931), p. 31.

be symmetrical but that their birefringence should be equal in all positions in the zone perpendicular to the K axis. Manolescu showed that this condition is not always fulfilled, and in one instance of haveno twinning, in which determination by means of the position of the composition plane indicated a difference of 20 per cent. in the anorthite content of the two hemitropes, showed that there was a difference of 3° between the positions of the composition and symmetry planes, and that determination by means of the symmetry plane gave concordant results for the two hemitropes.

In the determination of normal twins, small deviations, varying from $\frac{1}{2}^\circ$ to 3° , were frequently found by the author, and in text figure 12 (page 240) the poles of both composition and twin planes are given for all cases in which the deviation amounted to more than 1° . From this diagram, in which related poles are connected by lines, it will be seen that with one exception, the approximation of twin planes to the curves is greater than that of the composition planes. In other words, the scattering of the poles is reduced, but not entirely eliminated, by plotting the poles of twin planes instead of composition planes. A similar phenomenon was observed by Spaenhauer¹, who compared the poles of albite twin planes, obtained by the constructional method of Nikitin², with the poles of composition planes obtained by direct measurement.

In the case of parallel and complex twinning, the planes of composition and twinning should not coincide, and in these cases the plane of twinning is usually not directly determined by the Fedoroff method. The pole of the twin axis, which is normal to the twin plane, is however obtainable by the Nikitin method of construction but since the poles of composition planes and twin axes lie on or near different curves, their distribution is not directly comparable, as in the case of normal twinning. It was, however, shown by Spaenhauer, that the scattering of the poles of twin axes of parallel and complex twins is less pronounced than is the case with poles of composition planes of the same twins. In the author's investigation, the primary purpose of which was the determination of the anorthite value and the establishment of the twinning law, the poles of twin axes were not determined in all instances. Those which were determined are shown in Plate 31, a comparison of which

¹ F. Spaenhauer, *loc. cit.*, pp. 360-362.

² W. W. Nikitin, 'Korrekturen und Vervollständigungen der Diagramme zur Bestimmung der Feldspate nach Fedorows Methods', *Min. Petr. Mitt.*, Bd. 44, (1933).

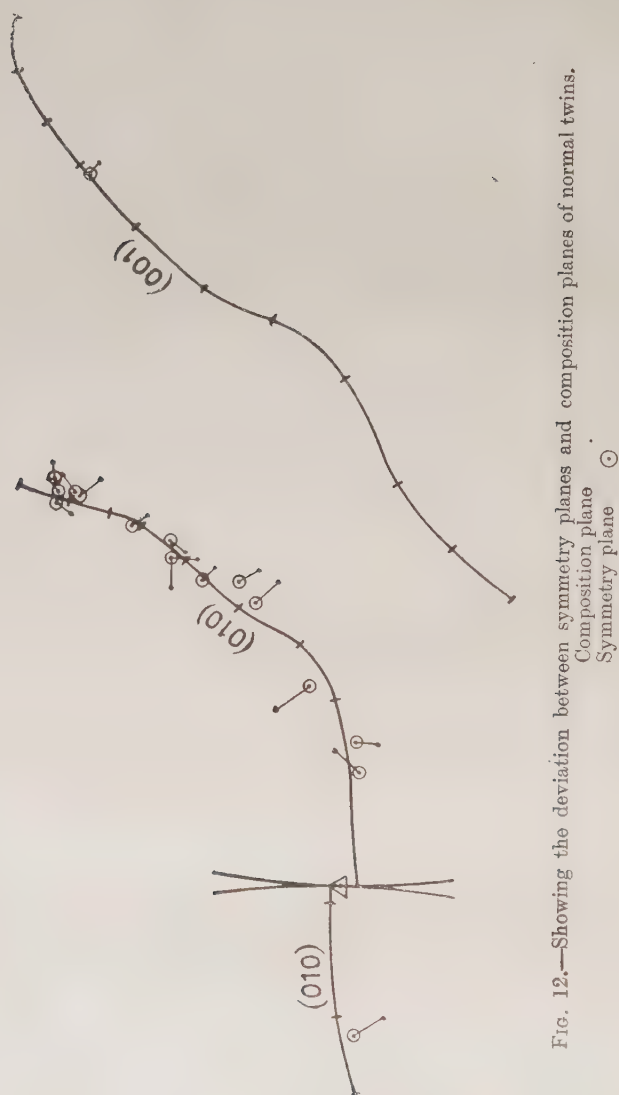


FIG. 12.—Showing the deviation between symmetry planes and composition planes of normal twins.

with figures 9, 10 and 11, showing the distribution of the poles of composition planes, supports the conclusion that the scattering of the poles of twin axes is less pronounced than that of the poles of composition planes.

Dr. A. E. H. Tutton¹ states :—

‘ In the case of “ juxtaposition twins ” the plane of union, whether the twin plane or not, is known as the “ plane of composition ”. “ Interpenetration twins ”, however, have no plane of composition. Hence *the only true elements of twinning are the twin plane and the twin axis.*’

The twins of plagioclase, or at least such as we are concerned with, belong to the class of ‘ juxtaposition twins ’ in which the plane of composition is more or less perfectly realised, and corresponds to, or approximates to, a possible crystal face with low rational indices. From the frequently observed discrepancy, however, between the twin and composition planes of normal twins, and the more pronounced scattering of the poles of composition planes than those of twin axes, Manolescu² concluded that this ideal composition plane is less perfectly realised than the twin plane and twin axis, which Tutton regards as the true elements of twinning. In other words, *the plane of composition is frequently a vicinal plane.* Furthermore, since the correspondence between the poles of twin planes and the curves is greater than between the poles of composition planes and the same curves, the conclusion that the scattering of the latter is partially due to vicinal phenomena is inevitable.

In view of the above conclusion, a more complete knowledge of vicinal phenomena in the feldspars is of great importance from the point of view of their accurate determination. Most of the published work on vicinal problems deals with cubic or hexagonal crystals, which as a result of their higher symmetry are more amenable to investigation. It is, therefore, the more unfortunate that the only paper which is exclusively devoted to vicinal phenomena in the feldspars, should be characterised by an indiscriminate application of geometric principles to a preconceived hypothesis which entirely obscures the true nature of the problem.

In their paper entitled ‘ Quelques courbes nouvelles pour la détermination des Feldspaths par la methode Fedoroff ’, H. Sigg and

¹ A. E. H. Tutton, ‘ Crystallography and Practical Crystal Measurement ’, Macmillan, p. 420, (1911).

² *Loc. cit.*, p. 461.

G. Favre,¹ regard every possible face in the zones (001) (100), (001) (010), (100) (010) and (001) (110) as a vicinal face, and on this basis have constructed, for the determination of the feldspars, a most complicated stereogram of the type which has done so much to discourage the use of the Fedoroff method by English petrologists. The interpretation placed by these authors on the term 'vicinal face' is so foreign to the accepted conception of faces of high indices lying very near to simple faces of low rational indices, that their paper can but be regarded as of negative value as a contribution to the real problem of vicinal phenomena in the feldspars.

The important aspects of the subject, from the point of view of the accurate determination of the feldspars, are:—(a) whether vicinal faces are restricted to, or have a predilection for, any particular zone, (b) the degree of deviation in the feldspars of the vicinal zones, such as were established by Kalb² in connection with his researches on cubic and hexagonal crystals, from true zones, and (c) the direction and constancy of the deviation. Our present knowledge of vicinal phenomena in the feldspars is inadequate to permit even the broadest generalisations on these subjects. It appears, however that the examination of specially prepared sections of feldspars, of more than standard thickness to enable a more precise orientation of the composition planes on the universal stage, and the macroscopic study of vicinal faces on hand specimens of the feldspars, may prove a fruitful field of research.

Before leaving this subject, it should be mentioned that it is not considered that vicinal phenomena play a part in the scattering of cleavage poles. Vicinal faces are widespread phenomena connected with the growth of the crystal, but cleavage is a secondary phenomenon controlled by internal fine structure. Not only is there no evidence that cleavage planes are other than true crystallographic planes, but there are strong theoretical grounds for the belief that they must correspond to such planes. Tutton³ writes:—

'Now all the evidence up to the present accumulated goes to show that the commonest faces characteristic of a crystallised substance are those parallel to planes most densely strewn with points, that is, with structural units, be they considered as whole molecules or groups or of specific atoms; also that the cleavage planes correspond to those planes of the space-lattice which are most widely separated from each other. For obviously the cohesion should be a minimum between

¹ *Bulletin de la Société Vaudoise des Sciences Naturelles*, Vol. LI, pp. 341-380, (1917).

² G. Kalb, *vide* quotation on page 237.

³ A. E. H. Tutton, *loc. cit.*, p. 530.

particles at the greatest distance apart, and a maximum between those nearest together, in accordance with the universal law of inverse squares applying to forces of this description between particles. Hence, the fact that the directions of cleavage are usually those of the commonly developed crystal forms is in perfect agreement with the theory of crystal structure. It also now becomes perfectly clear why cleavage can only occur along certain specific plane directions identical with forms of low indices, for it can only occur along a plane or planes of the space-lattice.'

From the above quotation, it may be argued that crystal faces are no less the external expression of internal fine structure than are cleavage planes. In the author's view, however, this thesis cannot be maintained. Miers¹ attributed vicinal phenomena to the fact that surfaces of great reticular density are not, in fact, realised as faces, and states :—

'In any case, the fact to which I wish to draw attention is that the faces which actually occur upon a crystal are not those with simple indices and great reticular density, but those with complex indices and low reticular density.'

The status of cleavage, however, appears quite different, and M. J. Buerger² states :—

'Similarly, it has been shown by Huggins, Wooster, and many others that the cleavage characteristics of crystals are determined by their respective fine structures.'

In this connection, Dr. W. N. Bond³ has shown that in the case of muscovite, cleavage flakes are of uniform thickness certainly to 8×10^{-8} cm. and probably to 2×10^{-8} cm. or less.

Attention has been drawn by F. Zwicky⁴ to imperfections in the fine structure of crystals, and H. Tertsch⁵ has shown that cleavage is very susceptible to these imperfections. This, however, merely serves to emphasise the complete dependence of cleavage on fine structure, since these abnormalities are of a totally different order of magnitude than the deviation of vicinal faces from true crystallographic planes, and R. W. James⁶ has shown that dislocations

¹ H. A. Miers, 'An Enquiry into the Variation of Angles observed in Crystals, especially of Potassium-alum and Ammonium-alum', *Phil. Trans. Roy. Soc., Ser. A.*, Vol. CCII, p. 521, (1904).

² M. J. Buerger, 'The Nonexistence of a Regular Secondary Structure in Crystals', *Zeitschr. Krist.*, Bd. 89, Ht. 3/4, p. 255, (1934).

³ W. N. Bond, 'The Perfection of Crystal Laminae', *Phil. Mag.*, Ser. VII, Vol. XVI, pp. 410-422, (1933).

⁴ F. Zwicky, 'On the Imperfections of Crystals', *Proc. Nat. Acad. Sci.*, Vol. XV, pp. 253-259, (1929).

⁵ H. Tertsch, 'Der derzeitige Stand des Spaltbarkeitsproblems', *Centralbl. Min., A.*, pp. 151-160, (1933).

⁶ R. W. James, 'The Intensities of X-Ray Spectra and the Imperfections of Crystals', *Zeitschr. Krist.*, Bd. LXXXIX, Ht. 3/4, pp. 295-309, (1934).

amounting only to a fraction of a lattice spacing are sufficient to account for the phenomena.

The conclusion that vicinal phenomena do not play a part in the scattering of cleavage poles does not detract from the conclusion that they are partially responsible for the scattering of the poles of composition planes, since, as stated above, the scattering of cleavage poles is slightly less pronounced than in the case of composition planes in spite of a greater factor of experimental error in their determination.

The determinative curves of Reinhard, and indeed all similar curves showing the migration of the indicatrix in the crystal, or *vice versa*, the wandering of morphological poles with reference to fixed optical elements, are based on the conception of the plagioclase feldspars as binary systems, consisting of varying proportions of the components albite and anorthite. This does not necessarily mean that the authors considered plagioclase feldspars to be in fact binary systems, but rather that they were compelled to regard them as such in the imperfect state of our knowledge of the effect of other components on their optic properties. In their joint work, L. Duparc and M. Reinhard¹ state:—

The possible effect of components other than albite and anorthite on the orientation of the indicatrix.

‘ On donne le nom de plagioclases à des mélanges isomorphes en toutes proportions d'albite, Ab, de formule $\text{Na Al Si}_3 \text{O}_8$, et d'anorthite, An, $\text{Ca Al}_2 \text{Si}_2 \text{O}_8$. Dans la règle on admet que ces deux termes seulement se mélangent. Pratiquement, l'analyse montre fréquemment la présence de $\text{K}_2 \text{O}$ en petite proportion dans des plagioclases parfaitement purs. Il est donc probable qu'il existe un terme potassique ayant une formule analogue soit à l'albite, soit à l'anorthite, susceptible de se mélanger en quantité variable aux deux précédents. D'autre part, Washington et Wright semblent avoir trouvé en mélange isomorphe avec les plagioclases une anorthite sodique répondant à la formule $\text{Na}_2 \text{Al}_2 \text{Si}_2 \text{O}_8$, à laquelle ils ont donné le nom de Carnegieite. Néanmoins l'influence de la potasse et de la Carnegieite est encore trop mal connue pour qu'on puisse en tenir compte, et dans la pratique, on se borne à envisager l'albite et l'anorthite seulement.’

And²:—

‘ Nous avons choisi, si possible, des types de plagioclases ne contenant pas de potasse.’

¹ L. Duparc et M. Reinhard., ‘ La Détermination des Plagioclases dans les Coupes Minces ’, *Mém. Soc. de Physique et d'Histoire Naturelle de Genève*, Vol. XL., p. 4, (1924).

² *Loc. cit.*, p. 5.

This statement has been criticised by Alling¹ who states:—

‘The feldspars belong to a five component system, of which the end members are the potash, soda, lime, barium, and carnegieite feldspars. For most purposes it is only necessary to consider the potash, soda, and lime components. Every specimen of feldspar found in nature contains a certain amount of each of these three components.’

And, as a result of the examination of nearly 1,300 analyses of feldspars²:—

‘All plagioclase specimens contain some potash component; the average is in the neighbourhood of 5 per cent. It is more accurate to assume that the potash component is present to this extent than it is to ignore it altogether.’

In a subsequent paper, the same author states³:—

‘If the potash mineral is actually absent, then the data represent unusual feldspars which cannot be employed in setting up determinative curves for average specimens.’

He does not, however, accept the view that potash was indeed absent from these feldspars, and in a still later paper⁴ recasts the analytical data used by Duparc and Reinhard to include percentages of potash ranging from 2 to 7.45.

In his more recent work on the determination of the feldspars by the Fedoroff method, Professor Reinhard⁵ recognises the cogency of this criticism, and mentions varying percentages of potash as a possible cause of the scattering of the poles. As a result, however, of the cumulative experience gained by the Basel school of investigators, Professor Reinhard⁶ also wrote at that time:—

‘*Man darf mit einer gewissen Wahrscheinlichkeit annehmen, dass die Einlagerung von Or-Molekülen in das Plagioklasgerüst die Lage der Indikatrix nur wenig beeinflusst, dass sie hingegen die Form derselben infolge der Lockerung und Aufweitung des Gitters stärker in Mitleidenschaft zieht. Die Brechungsindizes werden deshalb stark durch den Kaligehalt beeinflusst, und die Bestimmungsmethode, die auf der Feststellung derselben beruht wird unzuverlässige Resultate über den Anorthitgehalt liefern.*

Da die Fedoroffmethode die Lage der Indikatrix im Kristallgebäude benützt, um sowohl die Zwillingsgesetze als auch den Anorthitgehalt eines Plagioklases zu

¹ H. L. Alling, ‘The Mineralogy of the Feldspars’, *Journal of Geology*, Vol. XXIX, p. 290, (1921).

² H. L. Alling, *loc. cit.*, p. 292.

³ H. L. Alling, ‘The Indices of Refraction of the Plagioclase Feldspars’, *Journal of Geology*, Vol. XXXVII, p. 473, (1929).

⁴ H. L. Alling, ‘Feldspars in the Adirondack Anorthosite’, *The American Mineralogist*.

⁵ M. Reinhard, ‘Universal Drehtischmethoden’, Basel, pp. 11-118, (1931).

⁶ M. Reinhard, *loc. cit.*, pp. 111-112.

⁷ The italics are mine.

bestimmen, dürfte sie die zuverlässigsten Bestimmungen ergeben. Eine Verbindung beider Methoden scheint uns zur Vertiefung unserer Kenntnisse sehr angebracht. Man würde wahrscheinlich feststellen können, dass die Bestimmung nach der Fedoroffmethode einen höheren Gehalt an Anorthit ergibt als die Brechungsexponentenmethode und dürfte daraus mit grosser Wahrscheinlichkeit auf einen Or-Gehalt schliessen.'

This conclusion, that the orientation of the indicatrix is but little affected by the potassium content, is supported by all the subsequent evidence obtained in the Basel school. The most important of this more recent evidence is to be found in the work of Spaenhauer¹, who, as a result of the determination of synthetic anorthite by the Fedoroff method, showed that the scattering of the poles was commensurate with that obtained in the case of natural feldspars. A second slide of feldspars, synthesised from a mixture of anorthite and ten per cent. of potash feldspar, showed a similar scattering of the poles, which, however, were concentrated still more towards the anorthite end of the curves than in the case of the pure anorthite. In this case, however, the evidence of the effect of the potash content on the orientation of the indicatrix, is obscured by the doubt as to whether the potassium really entered into the composition of the feldspars which were investigated, as the slide contained a cryptocrystalline residue which was indeterminable. The same doubts apply with even greater force to four other slides of feldspars synthesised from varying proportions of anorthite, albite and carnegieite which were investigated by the same observer.

The fact that the most meticulous determination of synthetic anorthite yielded poles with a field of scattering comparable to that obtained in the case of natural feldspars, does warrant the conclusion that the effect of the potash content on the orientation of the indicatrix is slight. The exact nature and magnitude of the effect, however, are still open questions, and the following remarks of Professor Reinhard² are as true to-day as when they were first written:—

'Die kritischen Bemerkungen die Alling dieser Frage widmet, sind leider nur zu berechtigt. Es wird eine dankbare aber auch sehr schwierige Aufgabe sein, neue zuverlässige optische und chemische Bestimmungen an Plagioklastypen vorzunehmen. Wer sich mit solchen Untersuchungen abgegeben hat wird wissen, wie ausserordentlich schwierig es ist geeignetes, reines und homogenes Material in genügender Menge zu beschaffen. Vielleicht wird es der Mineralsynthese gelingen die erforderlichen Untersuchungsobjekte herzustellen, mit denen uns die Natur so kärglich bedacht hat.'

¹ F. Spaenhauer, *loc. cit.*, p. 358.

² M. Reinhard, *loc. cit.*, pp. 105-106.

From the foregoing review of the evidence, it appears that after allowing for inaccuracies of measurement and eliminating the effects of vicinal phenomena, by considering

The possible effect of physical factors on the scattering of the poles. the distribution of the poles of cleavage, twin planes and twin axes, there remains a residue of scattering of the poles for which varying

percentages of potash, or other still rarer component, are unable to account. There remains one other hypothesis, which has not previously been considered in this connection, which is capable of explaining this residue of scattering of the poles, whether of composition, twin or cleavage planes, or of twinning axes. That is, that slight variations in the orientation of the optical indicatrix are produced by purely physical conditions of crystallisation, or by physical changes to which the feldspars have been subjected subsequent to crystallisation.

About variations in the physical conditions of crystallisation of the feldspars very little is accurately known, but T. F. W. Barth¹ has shown that there was a 'pronounced change of both the position and shape of the optical indicatrix' in the case of labradorite after heating at 1,000° for 300 hours.

The better to compare the magnitude of this effect with the observed scattering of the poles obtained by determination according to the Fedoroff method, I have carefully enlarged the stereographic projection given by Barth to twenty centimetres diameter, to conform to the other text figures given in this paper, and have also transposed this stereogram, originally projected on [010], to a projection perpendicular to $n\beta$, to correspond to Plate 2 of Reinhard's determinative stereograms (reproduced as Plate 30 of this paper). The (010) and (001) poles of the stereographic projection thus obtained are given as text figure 13, from which it will be seen that the original poles correspond very closely with the curves and indicate a composition of 45 per cent. An. The poles derived from data obtained after subjection to heat lie five millimetres from the curves, and if interpreted by dropping perpendiculars to the curves, indicate a composition of over 50 per cent. An. It may be significant that they both lie to the right of the curves, as the deviation from the curves of the majority of the poles obtained by Fedoroff determination is in the same direction, particularly with feldspars of this composition. The magnitude of the deviation of the poles from the

¹ T. F. W. Barth., 'Permanent Changes in the Optical Orientation of Feldspars Exposed to Heat', *Norsk Geologisk Tidsskrift*, Vol. XII, pp. 57-72, (1931).

curves is also commensurate with that shown by text figures 9, 10 and 11 and by similar diagrams of other investigators. It is clear that physical changes to which feldspars are subjected are capable, not only of producing deviation of the poles from the determinative curves, but also of leading to erroneous conclusions as to their composition. Whether such changes are capable of producing scattering of the poles, depends on the variability of the magnitude, and to a lesser degree of the direction of displacement of the optical symmetry axes.



FIG. 13.—Showing the effect of heating to 1,000° on the orientation of the indicatrix in labradorite.

◇ Original poles.

⊙ Poles after heating at 1,000° for 300 hours.

Barth¹ has also conducted experiments with potash feldspars and with one specimen each of albite and oligoclase, and states that except for a slight increase of the axial angle, the properties of albite and oligoclase are not changed by heating. The results are, however, too meagre to permit of any conclusions as to the variability of the displacement of the indicatrix. Heating to 1,000° is, of course, very drastic treatment, and it is abundantly possible that heating at lower temperatures would cause the optical indicatrix in labradorite and other feldspars to assume positions intermediate between the initial and final positions determined by Barth. A series of experiments to determine whether this is so, and also the constancy or variability of the direction of the displacement of the poles in feldspars of varying composition, would be of great interest from the point of view of the determination of the feldspars by the Fedoroff method, and at least offers a possibility of explaining the residue of scattering of the poles for which previous hypotheses have failed to account.

Since it has been demonstrated that the application of heat is capable in some instances of causing a displacement of the optical indicatrix, it is also possible that other physical factors may be capable of doing so, and investigation of the effects of varying pressures under which crystallisation takes place, may prove a fruitful field of research.

The pericline composition plane is unique among the composition planes in the feldspars in that it is a variable plane with irrational indices. The axis of pericline twinning is the crystallographic axis [010] but the composition plane varies with the chemical composition of the feldspars in such a manner that its intersection with the prism faces produces the so-called rhombic section. The supposed variation of the dihedral angle between the face (001) and the rhombic section in its dependence on the chemical composition of plagioclase, is shown by the curve in text figure 14, (see page 252) constructed by Dr. F. Coles Phillips² on the basis of Schmidt's³ assemblage of the Wülfing⁴ data.

¹ T. F. W. Barth, *loc. cit.*, pp. 67-72.

² F. Coles Phillips, 'Pericline and Acline Twins in the Acid Plagioclases', *Min. Mag.*, Vol. XXII, pp. 225-230, (1929-1930).

³ E. Schmidt, 'Chemie der Erde (1915)', Vol. I, pp. 351-406.

⁴ E. A. Wülfing, 'Sitzungsber. Heidelberg. Akad. Wiss., Math. Naturw. Kl., Abt. A, Abh. 13, (1918).

In 1928, T. F. W. Barth¹ published the data of fourteen determinations of the angle σ in acid plagioclases, showing very considerable deviation from the Wülfing values, and concluded that the position of the rhombic section while showing a tendency to a relationship with chemical composition, is not entirely controlled by this factor. This conclusion was criticised by F. Coles Phillips² on the grounds that the very low values determined by Barth are probably due to confusion of pericline twinning with acline or complex manebach-ala twinning, and who concludes that:—

‘In the true pericline twin, with variable composition plane, the high values of suggested by theory are actually met in practice, and the Wülfing curve is to be regarded as the true locus of the pole of this composition plane.’

In three papers published in 1930 and 1931, O. Mügge³ showed that in natural crystals of anorthite from Vesuvius the angle σ was found to be from 2°-4° lower than the expected values for feldspars of this composition, and further that the values of σ for twin lamellæ artificially produced by strain at room temperatures are higher by about 4° than the values for the natural lamellæ in the same crystals. On the basis of these observations it was suggested by Mügge that the position of the rhombic section is dependent on temperature as well as on chemical composition, and even that variations in the value of σ can be used as a ‘geological thermometer’. In the present state of our knowledge, the latter suggestion will probably be regarded with scepticism, but the conclusion that the position of the pericline face is influenced by *physical* as well as chemical factors appears inevitable.

The position of the pericline composition plane has also been discussed by F. Penta⁴ who, as a result of investigation of pegmatites from Paghelia, stated in the introduction to his paper that numerous determinations of the position of the pericline composition plane in acid

¹ T. F. W. Barth, ‘Die Lage des “rhombischen Schnittes”, bei sauren Plagioclases’, *Zeitschr. Krist.*, Vol. LXVIII, pp. 616-618, (1928).

² F. Coles Phillips, *loc. cit.*

³ O. Mügge, ‘Ueber die Lage des rhombischen Schnittes im Anorthit und seine Benützung als geologisches Thermometer’, *Zeitschr. Krist.*, Vol. LXXV, (1930), pp. 337-344; ‘Die Lage des “Rhombischen Schnittes” im Anorthit und die Benützung derartiger irrationaler Zusammensetzungsflächen von Kristallzwillingen als geologische Thermometer’, *Nachrichten der Gesellschaft der Wissenschaften zu Göttingen*, Fachgruppe IV, No. 3, pp. 219-226, (1930); ‘Einfache Schiebungen am Anorthit’, *Neues Jahrbuch f. Min.*, Bd., LXIV Abt. A, pp. 163-170, (1931).

⁴ F. Penta, ‘Studio petrographico della Pegmatite di Paghelia (Cantazaro Calabria). Con osservazione sulle leggi di geminazione di Pericline nell’ Albite e nel Microclino’ *Schweiz. Min. Petr. Mitt.*, Bd. XIII, pp. 187-203, (1933).

plagioclase by the universal stage methods of Fedoroff, Becke and Rittmann, gave results divergent from both the Wülfing and Becke determinations. The information given in the text is meagre, and in the one concrete example cited, it is not apparent what method of determination was employed, but, as the author states that the dihedral angle between the cleavage plane (001) and the pericline composition plane was $9\frac{1}{2}^\circ$, it is presumed that the direction (001) was determined in the same specimen. As Penta points out, the value of $9\frac{1}{2}^\circ$ for σ agrees much better with the Becke than the Wülfing value. The important point, however, is not the relative reliability of the Wülfing and Becke data (both may be safely assumed to be reliable for the particular specimens investigated by these authors) but that the value of σ is variable even in feldspars of the same composition.

Considerable deviations from the Wülfing values, and, as will be seen from the following table, considerable variations also in the value of σ in feldspars of the same composition, were observed by the author. The values given in the table were determined directly on the Fedoroff stage and represent the true dihedral angle between the pericline composition plane and (001), and, since in every case cleavage or composition planes on (001) were determined, there can be no question of confusion of pericline twinning with acline or complex manebach-ala twinning.

TABLE 7.—*Variations in the sign and value of the dihedral angle between (001) and the pericline composition plane in 35 feldspars.*

Composition of feldspar % An.					Sign and value of σ .
100	.	.	.	.	(—) 13, 17.
95	.	.	.	.	(—) 15, 14, $14\frac{1}{2}$, $14\frac{1}{2}$, $15\frac{1}{2}$.
90	.	.	.	.	(—) $15\frac{1}{2}$, $14\frac{1}{2}$, $12\frac{1}{2}$, $15\frac{1}{2}$, $13\frac{1}{2}$, 13.
85	.	.	.	.	(—) $7\frac{1}{2}$, 14, 14, 12, 11, 6, 10, $7\frac{1}{2}$.
80	.	.	.	.	(—) 8.
75	.	.	.	.	(—) 5.
70	.	.	.	.	(—) 7.
50	.	.	.	.	(—) 3.
35	.	.	.	.	2, $4\frac{1}{2}$.
30	.	.	.	.	5.
25	.	.	.	.	6, 4, $4\frac{1}{2}$.
20	.	.	.	.	7, 8.
5	.	.	.	.	24, $8\frac{1}{2}$.

The comparison of these values with the Wülfing curve is shown by text figure 14.

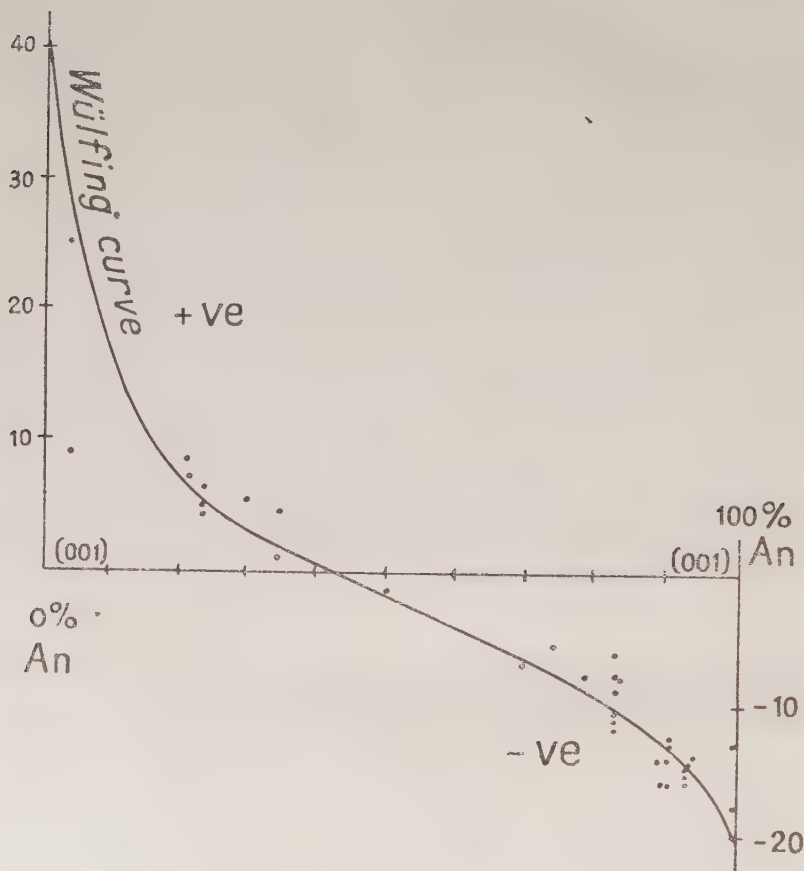


FIG. 14.—Showing the variation of the dihedral angle between (001) and the pericline composition plane.

The effect of the variations in the value of σ on the dispersion of the poles in the determinative stereogram is illustrated by text figure 15, in which all the pericline poles determined are given irrespective of whether the face (001) was determined in the same felspar.



FIG. 15.—Showing the position of the poles of the pericline composition plane with reference to the determinative curve.

It will be seen that the dispersion of the points is much greater than in the case of (010) and (001) poles (*see* text figures 9, 10 and 11). In the absence of (001) as a determinable direction, poles at the acid end of the curve can be interpreted in either the north-west or south-west quadrant of the stereogram (Plate 30 of this paper) and this may partially account for the very wide scattering of the poles at this end of the curve, but that this is not the complete explanation is shown by the fact that in the case of the poles denoted A and B the direction (001) was also determined. The pole denoted as (A) pertains to the pericline lamella in the felspar

figured in text figure 16 in which the poles of cleavage and of the albite, albite-ala and ala association planes and twinning axes were also determined.

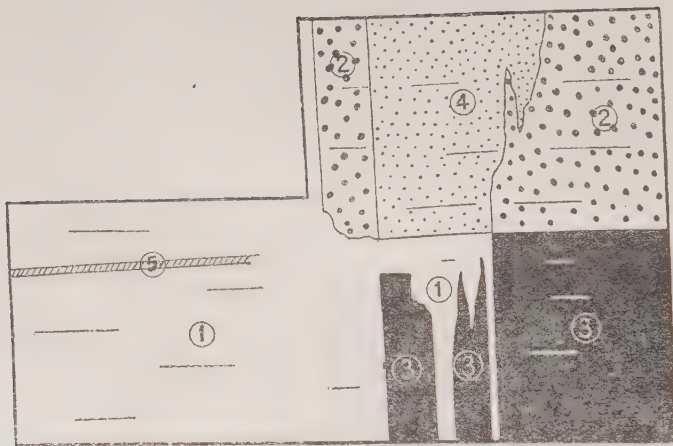
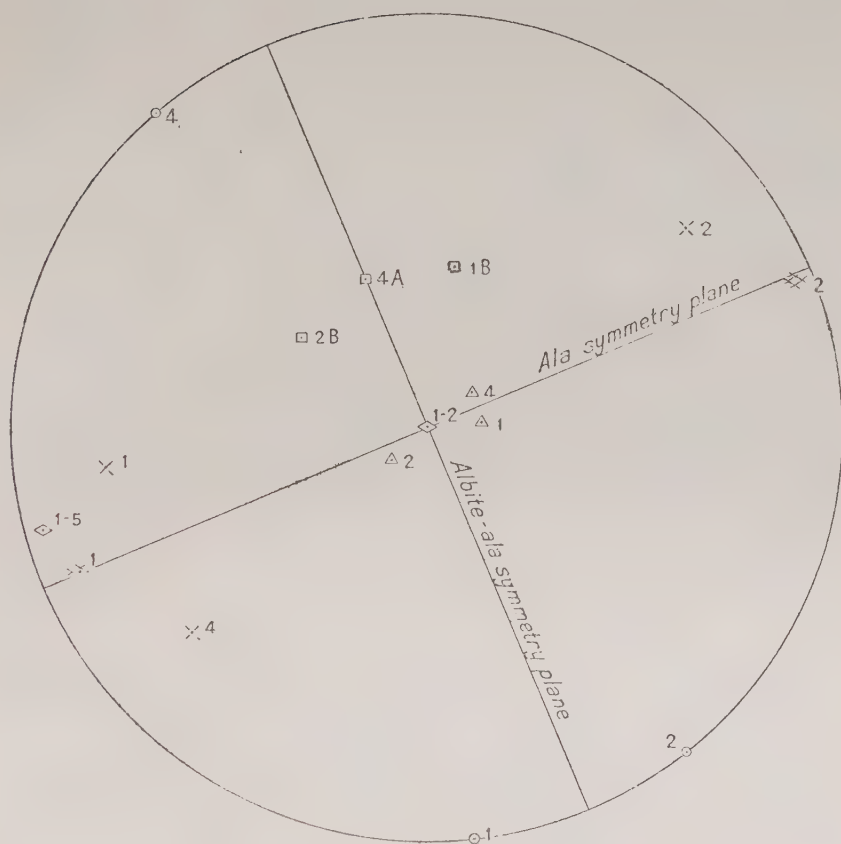


FIG. 16.—Illustrating an example of pericline twinning in which the dihedral angle between (001) and the pericline composition plane is remarkably small.

1—5 Pericline law.
 $\left. \begin{matrix} 1-3 \\ 2-4 \end{matrix} \right\} \text{Albite law.} \quad \left\{ \begin{matrix} 1-4 \\ 2-3 \end{matrix} \right\} \text{Ala law.}$
 1—2 complex Albite-Ala law.

The complete stereographic projection on (010) for this felspar is given as text figure 17, from which it will be seen that there can be no possible doubt that the lamella (5) is a pericline lamella.

Similar examples have been determined by other observers in the Basel school, where the results obtained suggest that any posi-



- = Pole of $n\alpha = np = x$
 × = Pole of $n\beta = nm = y$
 Δ = Pole of $n\gamma = ng = z$
 □ A = Pole of optic axis A
 □ B = Pole of optic axis B
 ◇ = Pole of composition plane
 ⊗ = Pole of cleavage

FIG. 17.—Projection on (010) of the optical and crystallographic poles of the feldspar depicted in text figure 16.

tion between the (001) and pericline curves of Plate II of the determinative stereograms (Plate 30 of this paper) may be occupied by the pericline pole, the field of which may be regarded as being determined by these two curves except of the basic end, where many poles fall beyond the pericline curve.

Text figures 14 and 15 both illustrate the unreliability of the pericline composition plane as a determinative direction and any method of determination based on it can be regarded only as the widest of approximations.

The production of secondary twinning on (010) and on the rhombic section under the influence of strain, has been conclusively demonstrated by the work of Mügge and Heide¹. The production of secondary twinning, due probably to the strain of the section-grinding process, was also observed by Alling², who also recorded the development of twinning in soda-orthoclase under the influence of heat. The development of twinning under the influence of strain is presumably due to simple gliding in a similar manner to the production of twinning in calcite by the well-known Baumhauer experiment. The subject has been discussed by Baier³, who concludes that the only forms of twinning which result from gliding are according to the albite and pericline laws:—

‘Es zeigt sich nun, dass als sekundär, d.h. Schieberzwillinge, nur solche mit Verwachsungsebenen (010) und rhombischem Schnitt vorkommen. Es ist von vornherein anzunehmen, dass die Zahl der Gesetze, nach denen bei den Feldspaten einfache Schiebung erfolgen kann, nur ganz klein ist; besonders wenn wir zu ultramikroskopischen Verhältnissen hinabsteigen scheint eine Verzwillingung der Bausteine nach den verschiedenen komplizierteren Gesetzen durchaus unwahrscheinlich. Und es kommen in der Tat nur Albit- und Periklingesetz vor. Zweifellos können sowohl Albitzwillinge mit M als Verwachsungsfläche als auch Periklinzwillinge mit dem rhombischen schnitt als Verwachsungsfläche als Schieberzwillinge erklärt werden. Das Albitgesetz stellt dabei eine Schiebung erster Art, das Periklingesetz eine Schiebung zweiter Art, dar, die beiden Schiebungen sind zueinander reziprok.’⁴

The same author considers that the question as to whether twinning according to these laws occurs as primary or growth

¹ O. Mügge und F. Heide, ‘Einfache Schiebungen am Anorthit.’, *Neues Jahrbuch f. Min.*, Bd. LXIV, Abt. A., pp. 163-170, (1931).

² H. L. Alling, ‘The Mineralogy of the Feldspars.’, *Journal of Geology*, Vol. XXIX, p. 210, (1921).

³ E. Baier, ‘Lamellenbau und Entmischungsstruktur der Feldspate.’, *Zeitschr. f. Krist.*, Bd. LXXIII, pp. 465-560, (1930).

⁴ E. Baier, *loc cit.*, p. 492.

twinning is not yet solved, but clearly regards primary twinning as very rare:—

‘Jedenfalls muss das fast völlige Ausfallen der Albit- und Periklinverzwillingung als Wachstumsform zu denken geben.’¹

The criteria, however, by which Baier distinguishes primary and secondary twinning appear to rest on somewhat precarious foundations and they are certainly not of universal application. The criteria proposed by him for the recognition of primary twinning are:—(a) that the composition face of primary twinning is rarely a plane and (b) that the development of primary twinning is reflected in the external morphological form of the crystal, as for example by the presence of re-entrant angles:—

‘Die älteste mögliche Generation ist der gewachsene Zwillung, er wird hier als Primär- oder Wachstumszwillung (W. Zw.) von allen übrigen Generationen abgeschieden. Er ist daran zu erkennen, dass seine Verwachsungsfläche meist nicht eben ist, häufig sogar recht lappig, mit weicher gekrümmter Spur im Schliff, wobei sich diese stark beeinflusst zeigt von allen wachstumsbedingten Erscheinungen, wie zonarem Bau, zonaren Einschlüssen usw. Sie steht auch meist in deutlicher Beziehung zu einem einspringenden Winkel der äusseren Umgrenzung.’²

As regards the former criterion, the author's experience is incompatible with the view that growth phenomena invariably or even usually result in the production of irregular faces. Zoning must certainly be regarded as a growth phenomenon, but in many of the zoned feldspars determined by me in the andesites, as for example those depicted in text figures 21, 23 and 24 below, the zoning directions are remarkable for their extreme regularity. I would, therefore, prefer to reject Baier's proposition and substitute the converse, *viz.*, *since secondary twinning, like cleavage, is determined by internal fine structure, the composition face should be both regular and a true crystallographic plane with low rational indices.* If, however, this proposition is accepted, pericline twinning, which Baier regards as most frequently secondary, must be regarded in many cases as primary, since in the author's experience and in that of other observers in the Basel school, pericline lamellæ are more frequently irregular than lamellæ twinned according to other laws.

If the above proposition is accepted also, all examples of twinning in which the composition face is a vicinal plane should be regarded as primary or growth twins. Sixteen of the seventeen examples,

¹ E. Baier, *loc. cit.*, p. 494.

² E. Baier, *loc. cit.*, p. 483.

the poles of which are given in the figure 12, in which the composition plane was shown by comparison with the symmetry plane to be a vicinal plane, are of albite twinning. The critical application of Baier's criterion, therefore, would appear to require the recognition of primary twinning according to both the pericline and albite laws, of the existence of which that author is apparently not convinced.

The second of Baier's criteria suffers from the fact that it is applicable only to rocks in which the feldspars have developed idiomorphic contours, that is the extrusive rocks, but even in such rocks it is questionable to what extent the final contour of the crystals is determined by growth and to what extent by resolution or corrosion, evidence for which is unmistakably visible in many examples of zoned crystals (*see* text figures 26 and 27, below). It would appear, therefore, that external form is valuable only as a positive criterion; where twinning does produce modification in the contour of a crystal, as for example in the feldspar figured in text figure 21 (page 264) it can only be regarded as primary, but the converse proposition, that examples of twinning in which there is no modification of the external form of the crystal are secondary, appears untenable. Incidentally, the example given in text figure 21 is twinned according to the albite law and provides a concrete example of primary albite twinning.

My own experience with regard to this matter may be summarised by the statement that, by applying the criteria of vicinal phenomena and of external morphology it has been possible to recognise many examples of twinning, including albite and pericline twinning, which it is considered must be regarded as primary. No example however, has been observed by me in which it has been possible to adduce infallible evidence of secondary twinning. I do not wish this statement to be interpreted as implying the absence of secondary twinning in the material studied by me, but merely that conclusive evidence of its presence is lacking.

Spurious symmetry planes.

In the case of normal twinning, the composition plane, when completely realised (*vide* page 239), corresponds with the twin plane, and in consequence, when the composition plane is oriented perpendicular to the K axis of the universal stage, the birefringence of the two hemitropes is equal in all positions during rotation about

this axis. In the case of parallel and complex twinning, the composition plane is not a symmetry plane, but in five examples of Carlsbad twinning, all with a composition of 85 per cent. An., the author observed that the birefringence of the two hemitropes remained equal in all positions during rotation about the K axis. Had this observation been relied upon for the determination of the twinning law, as is the case in the so-called 'Zone Method' of Rittmann¹, these five cases would have been interpreted as examples of normal twinning. Further investigation, however, established conclusively that these feldspars were twinned according to the Carlsbad law, and that the composition plane was not in fact a symmetry plane. This was most readily demonstrated by measuring the extinctions of the two hemitropes from the trace of the

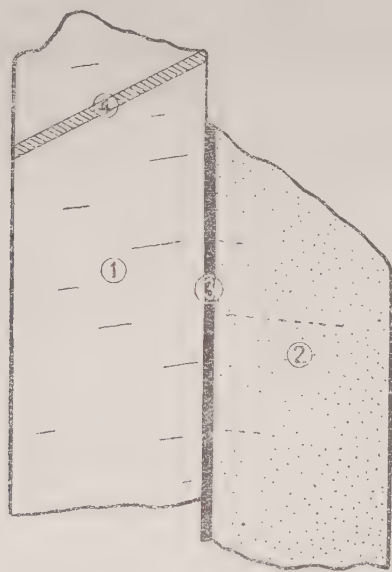


FIG. 18.—Illustrating an example of Carlsbad twinning in which the association plane appears to be, but is not, a symmetry plane.

1—2 Carlsbad law.

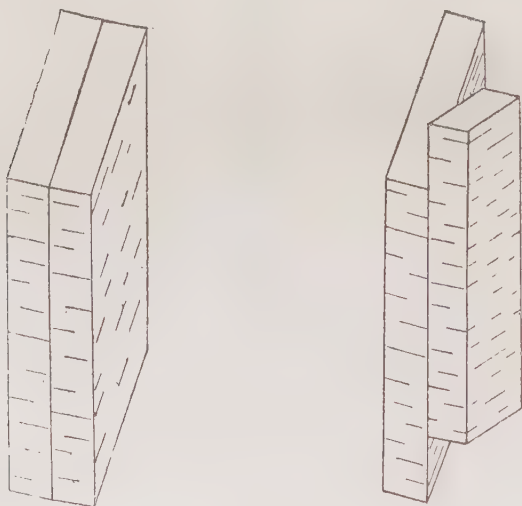
1—4 Pericline law.

Optics of lamella 3 indeterminable.

¹ A. Rittmann, 'Die Zonenmethode, ein Beitrag zur Methodik der Plagioklasbestimmung mit Hilfe des Theodolithischen', *Schweiz. Min. Petr. Mitt.*, Bd. IX, Ht. 1, pp. 1-46, (1929), and K. Chudoba (Translated by W. Q. Kennedy). 'The Determination of the Feldspars in Thin Section', Murby, London, (1933), pp. 38-61.

composition plane (010); they were found to be of opposite sign but of unequal magnitude. The composition plane, therefore, is no symmetry plane.

In one example, depicted in text figure 18 (page 259) cleavage on (001) is developed in both hemitropes. In the case of albite twinning, the composition plane being the twin or symmetry plane, the cleavage planes in the two hemitropes are symmetrically disposed to it, and, as will be seen from figure A. of text figure 19, the inclination of the cleavage planes in the zone perpendicular to (010) is the same. In other words, with the composition plane vertical, rotation about the K axis of the universal stage results in simultaneous orientation of the cleavage planes of the two hemitropes. In the feldspar under consideration this was found not to be the case, and there was a difference of 53° between their inclination in the zone perpendicular to (010). They are, therefore, in the position required by the Carlsbad law, which is illustrated by figure B of text figure 19.



A—Albite law.

B—Carlsbad law.

FIG. 19.—Illustrating the Albite and Carlsbad laws.

Finally, projection on (010) shows that the optical symmetry elements and morphological directions of the two hemitropes are

symmetrically disposed about the Carlsbad symmetry plane, as will be seen from text figure 20. When projected on this basis, corresponding poles of hemitropes twinned according to the albite law are centro-symmetrically disposed with reference to each other, and except in the case of very acid feldspars, and then only in the absence of cleavage, interpretation by means of this projection is unequivocal.

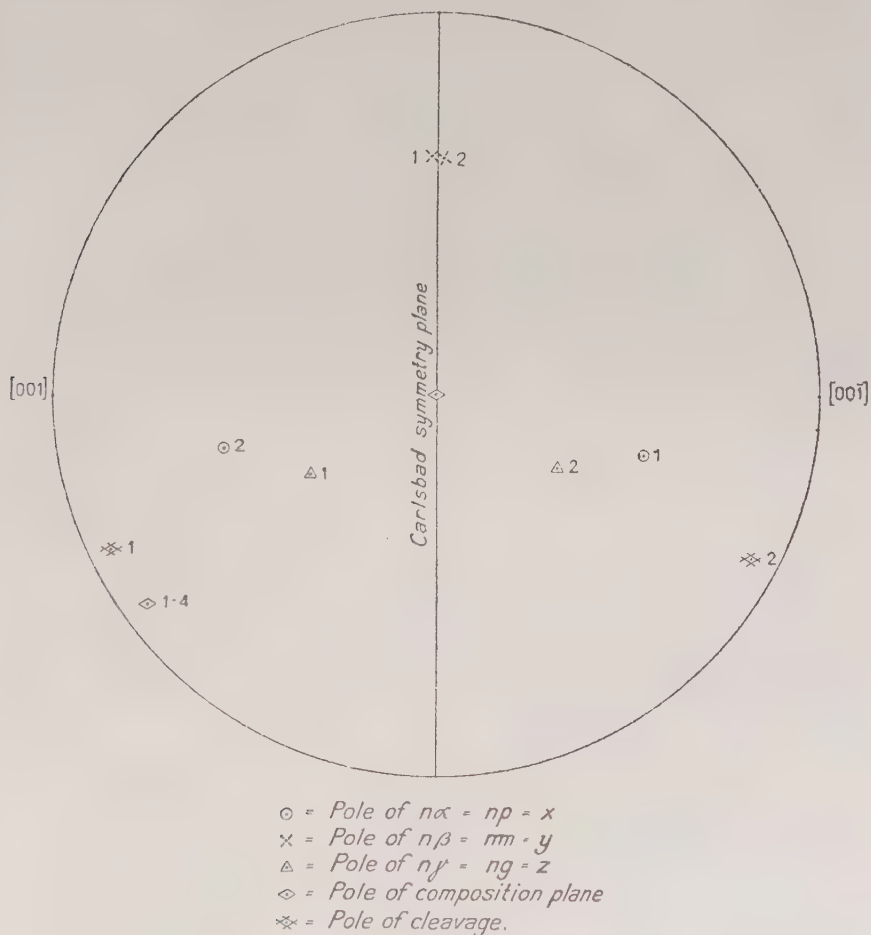


FIG. 20.—Projection on (010) of the optical and crystallographic poles of the feldspar depicted in text figure 18.

All five examples were investigated in this manner and it is quite clear that they are examples of carlsbad twinning. That the two individuals, therefore, show equal illumination in all positions of rotation about the K axis of the universal stage, with the composition plane perpendicular to this axis, is due not to the fact that the composition plane is a symmetry plane, but that in feldspars of this composition (85 per cent. An.) the birefringence of two hemitropes twinned according to the carlsbad law is equal in all positions in the zone perpendicular to (010). This phenomenon has not previously been recorded, and, as far as the author's experience goes, occurs only with feldspars of this composition. It illustrates, however, the danger of relying on curtailed procedure for the recognition of the twinning law.

Zoning.

Many of the feldspars in the andesitic rocks studied are characterised by zoning. Several examples were studied in detail and the composition of the individual zones was determined by the Fedoroff method in those cases in which their magnitude was sufficient to enable the orientation of the optical symmetry elements. In other cases in which many of the zones were too small to enable this procedure to be adopted, the composition of the larger was determined by the Fedoroff method and that of the smaller zones by determination of their extinction in the zone perpendicular to 010 (the so-called Zone method¹). The ranges of composition in the examples studied are shown by the following table in which only such examples have been included as permitted the determination by the Fedoroff method of at least two zones at the basic and acid ends respectively of their range of composition, and in which the extinction values in the zones so determined were concordant with the results of determination by the Fedoroff method.

TABLE 8.—*Variations in composition of zoned feldspars.*

Most basic zone % An.	Most acid zone % An.	No. of examples.
85	65	1
80	50	1
80	65	5
80	70	1
70	60	1
60	45	6
60	50	1
50	45	1

¹ A. Rittmann, *loc. cit.*

The subject of the variation in composition of zoned feldspars has been discussed by Coulson¹, Homma,² Paliuc³ and Phemister⁴. The last mentioned observer, as a result of his own investigations of Scottish basalts and a study of the publications of members of the Basel school, has proposed the following classification of zoning phenomena :—

- (a) *Normal*, in which there is a continuous and progressive decrease in basicity from the core to the margin of the crystal.
- (b) *Simple reverse*, in which there is a continuous and progressive *increase* in basicity from the core to the margin of the crystal.
- (c) *Oscillatory*, either *normal*, in which there is a general but interrupted decrease in basicity from the core to the margin, or *reverse*, in which there is a general but interrupted *increase* in basicity from the core to the margin of the crystal.

With possibly one exception, the examples of zoning studied by the author should be classified as *Oscillatory* (normal). *Simple Reverse* zoning was not observed, and in cases of oscillatory zoning, in which there are marked reversions to basic composition they invariably initiate a new cycle characterised by decreasing basicity towards the margin. A few examples which illustrate these features will now be discussed.

The feldspar figured in text figure 21 (page 264) is the nearest approach seen by the author to normal (*sensu stricto*) zoning. In this example the decrease in basicity from the core to the margin is progressive, but it is not continuous. The discontinuity is evidenced by the very fine sutures which separate the various zones. They are remarkably regular and sharply defined, and on the ordinary microscope stage are visible as concentric striations. On the

¹ A. L. Coulson, 'On the Zoning and Difference of Composition of Twinned Plagioclase Feldspars in Certain Rocks from Sirohi State, Rajputana', *Rec. Geol. Surv. Ind.*, LXV, pp. 164-171, (1931).

² F. Homma, 'Über das Ergebnis von Messungen an zonaren Plagioklasen aus Andesiten mit Hilfe des Universaldrehtisches', *Schweiz. Min. Petr. Mit.*, Bd. XII, pp. 345-351, (1932).

³ G. Paliuc, 'Untersuchungen der Plagioklase einiger tertiärer Ergussgesteine Siebenbürgens (Rumänien) mittelst der Universaldrehtischmethode', *ibid.*, Bd. XII, pp. 345-351, (1932).

⁴ J. Phemister, 'Zoning in Plagioclase Feldspar', *Min. Mag.*, Vol. XXIII, pp. 41-555, (1934).

universal stage it was possible to orient the planes of contact with a precision equal to that obtainable in the case of cleavage directions or association planes and the coordinates ϕ and ρ thus obtained, enabled the identification of the following faces as zonal

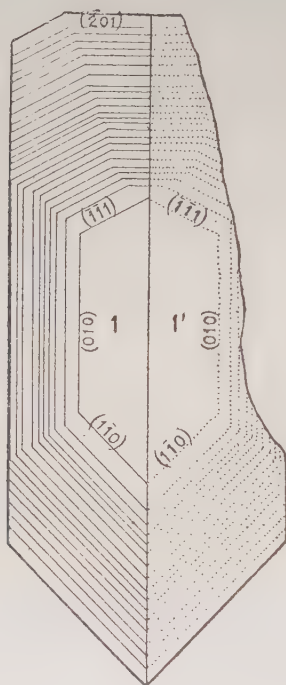


FIG. 21.—Illustrating zoning on (010), ($\bar{1}\bar{1}1$), ($1\bar{1}0$) and ($\bar{2}01$), and the great regularity sometimes seen in growth phenomena.
1—1' Albite law.

contacts:—($\bar{2}01$), ($\bar{1}\bar{1}1$), (010) and ($1\bar{1}0$). Their poles are denoted as 1 and 1a (for lamellæ 1 and 1' respectively) in the stereographic projection given as text figure 22 (page 265). This example illustrates the remarkable regularity which is sometimes seen in growth phenomena (*vide* page 257 *supra*), and furnishes also an example in which

albite twinning has exerted a dominant role in the morphological development of the crystal and must consequently be regarded as primary.

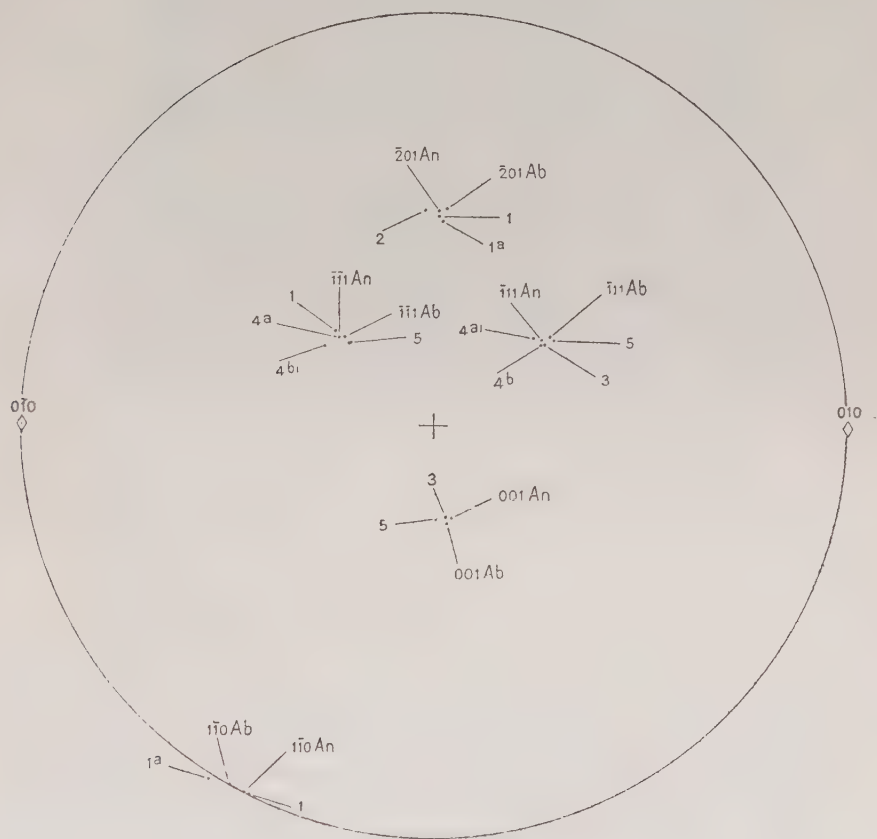


FIG. 22.—Projection on a plane perpendicular to $[001]$ showing the poles of zoning surfaces.

The other five examples which are illustrated by text figures 23 and 24, are characterised by oscillatory zoning.

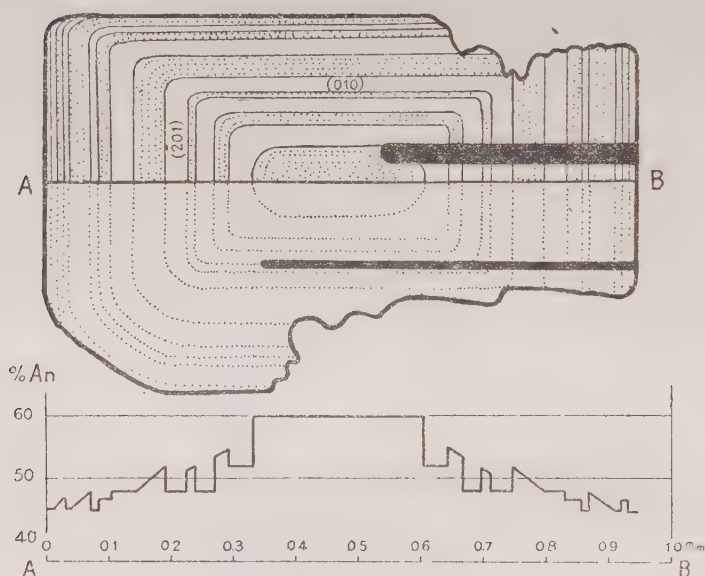


FIG. 23.—Illustrating oscillatory normal zoning.

Text figures 23 and 24 are given principally to illustrate the great regularity of the zonal contacts, which as in the case of the feldspar illustrated by text figure 21, were orientable with great precision. In the specimen illustrated in text figure 23, the faces (010) and (201) were determined as the zonal contacts and in that figured in text figure 24, the faces (010), (001) and ($\bar{1}11$). Their poles are denoted as 2 and 3 respectively in the stereographic projection given in text figure 22. The former furnishes a good example of oscillatory normal zoning, while the latter, viewed as a whole also an example of oscillatory normal zoning, is characterised by a local reversion of the normal sequen

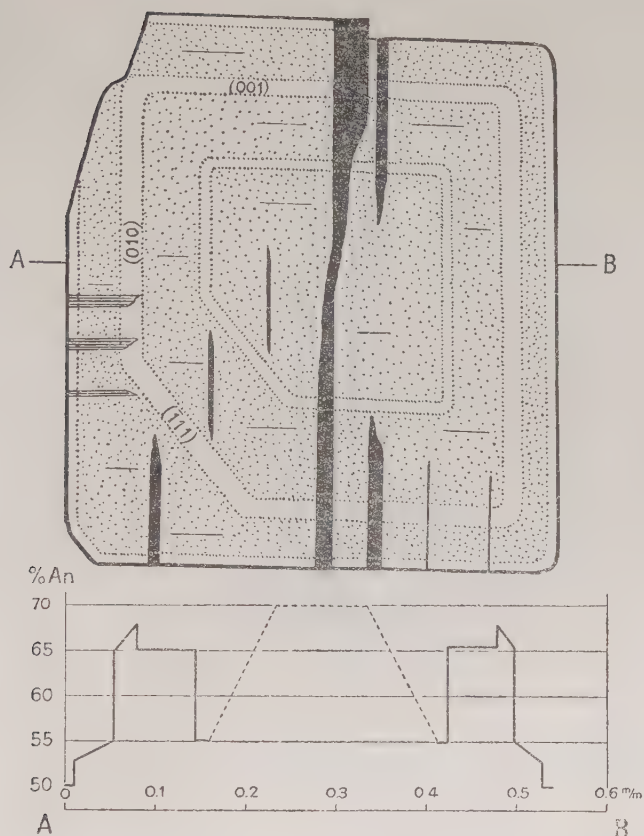


FIG. 24.—Illustrating zoning on (010), (001) and $(\bar{1}11)$, and the regularity sometimes seen in growth phenomena.

Text figure 25 (page 268) illustrates a very interesting feldspar in which the zonal contacts, although sharply defined and apparently extremely regular, present abnormal features which, it is thought, can be interpreted only as vicinal phenomena. The lamellæ 1' are in the albite relationship to lamellæ 1, and lamella 2 in the carlsbad relationship to lamella 1. The composition planes between the lamellæ do not, however, coincide with the albite symmetry plane, the trace of which is denoted by the direction XY in the text figure. The true angular distance between the morphological composition

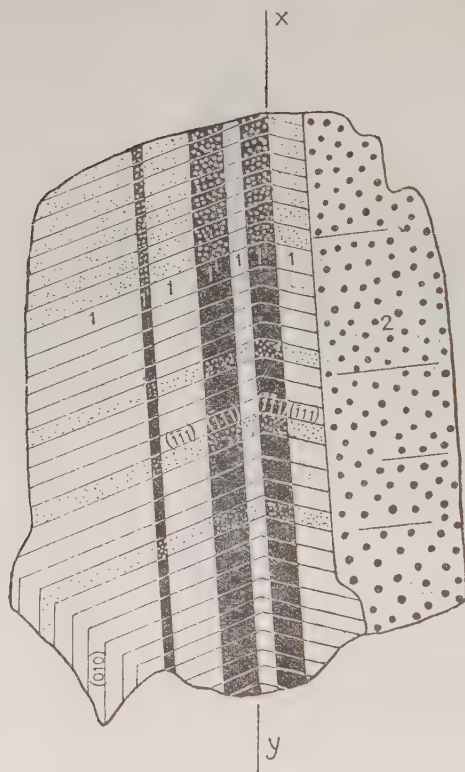


FIG. 25.—Illustrating an example of vicinal phenomena in a zoned felspar.
 64% Anorthite.
 70% Anorthite.

plane and the symmetry plane is $3\frac{1}{2}^{\circ}$. The felspar is traversed by three zoning directions which in spite of the very small variation in composition are characterised by sharply defined contacts which on the universal stage were orientable with great precision, in lamellæ 1 and 1'. In lamella 2, zoning is evidenced by wavy extinction but the zonal contacts were not orientable owing to their low inclination with reference to the plane of the section. Two of the systems of zoning in lamellæ 1 and 1' are inclined to the left and right respectively of the albite symmetry plane, while the third, restricted to lamella 1, is parallel to this plane. The remarkable feature of the two systems of zonal contacts inclined to the symmetry plane is that they traverse the albite lamellæ without interruption. Since the direction of zoning seen in the lower left hand corner of

the text figure is parallel to the albite symmetry plane the zonal contact is (010), while determinations of the directions inclined respectively to the left and right of the symmetry plane has led to their identification as the faces $(\bar{1}\bar{1}1)$ and $(\bar{1}11)$. Their poles are denoted in the stereographic projection given in text figure 22 as 4a and 4b respectively, and it will be seen that their approximation to the poles of $(\bar{1}\bar{1}1)$ and $(\bar{1}11)$ is very close. In lamellæ 1' twinned with lamellæ 1 according to the albite law, there is no face parallel to the faces $(\bar{1}\bar{1}1)$ and $(\bar{1}11)$ of lamellæ 1, but from Goldschmidt's data it is ascertainable that the face $(\bar{1}\bar{1}1)$ of lamellæ 1' should make an angle of 7° with the face $(\bar{1}\bar{1}1)$ of lamellæ 1; similarly the face $(\bar{1}11)$ of lamellæ 1' should make an angle of 7° with the face $(\bar{1}11)$ of lamellæ 1. The poles of the directions inclined to the left and right of the symmetry plane respectively, interpreted with reference to the optics of lamellæ 1' are denoted as 4a₁ and 4b₁ in text figure 22, from which it is seen that they approximate to but do not coincide with the poles of the faces $(\bar{1}\bar{1}1)$ and $(\bar{1}11)$, respectively. The explanation, therefore, of the continuity of these two directions of zoning in the systems 1 and 1' appears to be that the direction inclined to the left of the symmetry plane is $(\bar{1}\bar{1}1)$ in lamellæ 1 and a vicinal face to $(\bar{1}\bar{1}1)$ in lamellæ 1', while the direction inclined to the right of the symmetry plane is the face $(\bar{1}11)$ in lamellæ 1 and a vicinal face to $(\bar{1}\bar{1}1)$ in 1', or more probably, that they are vicinal faces in both systems of lamellæ. In short, that the zonal direction inclined to the left of the symmetry plane is a vicinal face to $(\bar{1}\bar{1}1)$ in lamellæ 1 and to $(\bar{1}\bar{1}1)$ in lamellæ 1' while the direction inclined to the right of the symmetry plane is a vicinal face to $\bar{1}11$ in lamellæ 1 and to $(\bar{1}\bar{1}1)$ in lamellæ 1'. This felspar, then shows two types of vicinal phenonema; twinning on a vicinal face to (010), and zoning on vicinal faces to $(\bar{1}\bar{1}1)$ and $(\bar{1}11)$. It is remarkable, however, that the third direction of zoning is the true crystallographic direction (010). Since the composition planes between the lamellæ 1 and 1' are vicinal faces, it is concluded that the twinning is primary (*vide* page 257 *supra*). The evidence points, therefore, to two types of growth phenomena on (010), one of which (twinning) took place on a vicinal face, and the other (zoning) on the true crystallographic face. It is considered that there is no fundamental absurdity or even improbability in this explanation, since twinning and zoning, although both primary, are two distinct phenomena; the former is due to the assumption by similar mole-

cules of dissimilar orientations, the latter to the assumption by dissimilar molecules of similar orientations.

In view of the last mentioned fact, a comparison of the degree of approximation of zoning and twinning planes respectively to true crystallographic planes is of interest. Vicinal phenomena in connection with twinning has already been discussed and is illustrated by text figure 12 (page 240). From text figure 22 (page 265), in which the poles of the zoning faces determined are given, some conception of the role played by vicinal phenomena in zoning may be inferred from the scattering of the poles, the number of which, however, is insufficient to warrant any statistical comparison with the dispersion of the poles of association planes seen in text figures 9 to 11.

In the examples of zoning already discussed, the planes of zonal contact were remarkable for their regularity which permitted their identification as crystallographic planes. Two examples of zoned felspars will now be considered in which the zonal contacts are remarkable for their irregularity.

In the specimen figured in text figure 26 the composition of zones (a) and (h) was determined by the Federoff method and found to be

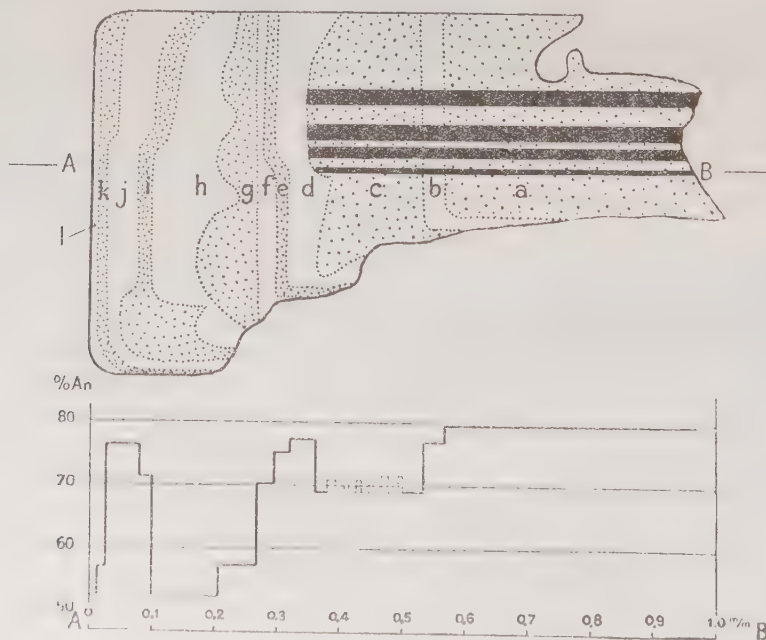


Fig. 26.—Illustrating oscillatory zoning accompanied by corrosion.

slightly less than 80 per cent. anorthite and slightly more than 50 per cent. anorthite respectively. The other zones of intermediate composition, were determined by means of their extinction values in the zone perpendicular to (010). The variations in composition are shown by the graph accompanying the text figure. The specimen is a fragment of a large crystal and from its general morphological development it is concluded that the core of the crystal is represented by zone (a) which is of uniform composition and the most basic of the determinable zones. It is followed by a narrow zone of slightly more acid composition and the sharpness and regularity of the zonal contact are thought to indicate an interruption of crystallisation unaccompanied by appreciable corrosion. Similar features are shown by the contact between zones (b) and (c) which mark further steps towards decreasing basicity. The extinction of zone (c) is wavy, indicating small fluctuations in composition which were not accurately determinable. It is followed by a more basic zone, and the corrosion deduced from the irregularity of the zonal contact is evidence of the instability of zone (c) in its more basic environment. Zones (e), (f) and (g) represent stages in the normal zonal sequence towards decreasing basicity and the slight irregularity of the zonal contacts between zones (d) and (e) and (e) and (f) are interpreted as reflecting the accretion of material on an irregular surface produced by the corrosion of zone (c), rather than as indicating further corrosion. Between zones (g) and (h) however, the pronounced irregularity of the contact is evidence of a prolonged break in crystallisation accompanied by corrosion. As zone (h) marks a further step in the normal zonal sequence it is considered that the break in crystallisation, and the corrosion which accompanied it, are due probably to temporary instability of the crystal due to a change in its physical rather than its chemical environment. Zones (i) and (j), however, mark a temporary reversion of the normal zonal sequence and the irregularity of the zonal contacts reflects the instability of the crystal in its more basic environment. With the return to the normal zonal sequence in zones (k) and (l) increasing regularity of the zonal contacts is again apparent.

Other aspects of zonal and corrosion phenomena are illustrated by the feldspar figured in text figure 27 (page 272) in which the composition of each of the zones was determined by the Fedoroff method. In this example the two hemitropes are twinned according to the

complex albite-carlsbad law. In view of its irregularity, the composition plane was not determinable, but the twinning law was

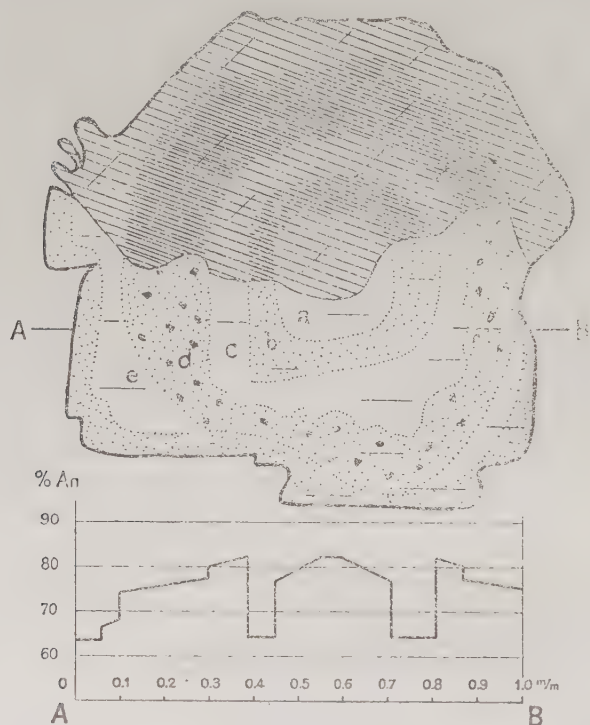


FIG. 27.—An example of complex Albite-Carlsbad twinning, and of normal oscillatory zoning accompanied by corrosion.

established by the construction of the twinning axis by the method of Nikitin. In this case the normal zonal sequence, initiated in zone (a) and continued in zone (b) was interrupted by the accretion of the more basic zone (c) in which, however, the normal sequence of decreasing basicity was recommenced and continued in the remaining zones. It is remarkable that in this specimen the most conspicuous evidence of corrosion does not occur at the contact between zones (b) and (c) which is characterised by a reversion of the zonal sequence, but between zones (c) and (d) in which the zonal sequence is normal and the difference in composition slight. It is considered, however, that regularity of the zonal contact is less reliable as a criterion of the absence of corrosion than angularity. In the specimen figured in text figure 24, above, the

absence of appreciable corrosion between the accretion of the successive zones, may be inferred from the combined regularity and angularity of the zonal contacts, in short from the fact that the contours of each of the zones are idiomorphic. In this example (fig. 27), however, corrosion may be inferred between the accretion of zones (a) and (b) and (b) and (c), and also between zones (d) and (e) and (e) and (f) by the rounding of the contours. Other interesting features of this crystal are, the abundance of inclusions in zone (d), which is thought to be due to rapid growth during a period of comparative stability in which there was but a slight and normal variation (*i.e.*, towards decreasing basicity) in the composition of the magma, and the fact that the final contour of the crystal is itself a solution and not a growth surface, as is unequivocally shown by its rounded and embayed form.

The phenomenon of zoning is due to the varying composition of the magma surrounding the growing crystal or to changes in the physical conditions of its environment. The subject of these variations, as evidenced by the complicated forms of zoning seen in the feldspars of extrusive rocks, is a fruitful field of speculation which has been explored by numerous authors whose views have recently been summarised by Phemister¹. As stated by this author:—

‘Continuous normal zoning is in accord with the theory of crystallisation from a melt of two components which form solid solutions in all proportions, and we may regard it as the normal product of crystallisation in an undisturbed magma, cooling slowly but not sufficiently slowly for the attainment of complete equilibrium.’

As pointed out by the same author, also, discontinuous or oscillatory zoning implies, therefore, some departure from these ideal conditions of crystallisation. The simplest variation from true normal continuous zoning is discontinuous normal zoning unaccompanied by corrosion, an example of which is illustrated by text figure 21 (page 264) above. This type of zoning has also been discussed by Phemister² who states:—

‘It seems that we should postulate some change in physical or chemical conditions which would cause a sudden change in the composition of the material precipitated without affecting that already crystallized. Removal of the crystal to a hypothetical less calcic part of the magma does not appear to be a probable explanation. Presumably this would involve an upward movement effected against gravity by convection currents, for the sudden origin of which it would still be necessary to provide an explanation. Further, unless the transportation were very

¹ J. Phemister, *loc. cit.*

² J. Phemister, *loc. cit.*, pp. 543-544.

rapid there should be continuous change between the inner and outer portions. Influx of more sodic magma may be suggested, but if the temperature remained the same, corrosion of the crystallized material should be expected to take place. A possible explanation which appears to give the required suddenness and proper direction of change in the physico-chemical conditions is that the magma, owing to relief by pressure consequent on eruption of overlying magma with which it is in hydrostatic communication, loses some of the volatile constituents.¹

The case of oscillatory zoning is more complicated and the various hypotheses advanced by Harloff¹, Harker², Iddings³, Fenner⁴, and Homma⁵ have been summarised by Phemister⁶ as follows:—

'The various hypotheses invoke recurrence of the following incidences separately or in some combination: (a) movement of crystals in the magma, whether by gravitative settling or by convection currents. (b) Movement of the magma as a whole into a region where different conditions of temperature and pressure prevail. (c) Irruption of additional magma into the crystallizing liquid. (d) Loss of volatile constituents.
Relief of pressure will result in loss of volatiles to an extent depending on the openness of communication between magma chamber and the throat of the volcano. So far as loss of volatiles can directly affect the nature of the plagioclase deposited the difference must lie towards the more sodic end. More calcic plagioclase can not separate out as the direct result of loss of volatile components. Relief of pressure causing streaming upwards of volatiles may, as suggested by Homma, aid circulation of crystals within the magma chamber.
Relief of pressure consequent on eruption must find an echo in the tendency of magma at lower levels to ascend to higher. It is, therefore, possible and probable that ascending hot magma will be erupted into higher chambers in which crystals are forming. It is by periodic accession of such hot magma that the writer would explain the abrupt recurrence of the more calcic zones which form the inner shells of the main zones of oscillatory-zoned crystals, the abrupt appearance of thin highly calcic shells, and the phenomenon of outer zones more calcic than the core.'

The Comparison of Other Methods of Determination with the Fedoroff method.

During the investigation of the feldspars by the Fedoroff method, attention was paid to the question of their determination by other methods, and certain comparisons of the results obtained by these

¹ C. Harloff, 'Zonal Structure in Plagioclases', *Leidsche Geol. Mededeel.*, II, pp. 100-113, (1927).

² A. Harker, 'Natural History of Igneous Rocks', London (1909), p. 232.

³ J. P. Iddings, 'Igneous Rocks', New York (1909), Vol. I, p. 177.

⁴ C. N. Fenner, 'The Katmai Magmatic Province', *Journ. Geol.*, XXXIV, pp. 700-703, (1926).

⁵ F. Homma, *loc. cit.*, pp. 350-351.

⁶ J. Phemister, *loc. cit.*, pp. 553-554.

methods with those obtained by Fedoroff determination are possible. The three other methods investigated are:—(a) The method of relative refringence (the so-called Becke method¹), (b) determination by means of the magnitude and sign of the optical angle, and (c) determination by the so-called Zone method.²

The scope of the Becke method is limited, but in favourable circumstances it can be used to distinguish broad groups of feldspars.

The Becke method. A sub-division which is widely applicable by

this method is that of feldspars with an anorthite content of less than 22 per cent. from the anorthite rich members of the series. This is effected by a comparison of their refractive indices with that of canada balsam and depends on the fact that the lowest refractive index ($n\alpha$) of all feldspars with an anorthite content of more than 22 per cent. is higher than the refractive index of canada balsam. Any feldspar, therefore, with a refractive index less than canada balsam is recognisable as albite or acid oligoclase. By a comparison of the refractive indices of feldspars with those of quartz, feldspars with an anorthite content of less than 48 per cent. can be distinguished by the fact that their lowest refractive index (α) is lower than the greatest refractive index ($n\gamma$) of quartz, and it is further possible by a comparison of their highest and lowest refractive indices with those of quartz to subdivide the feldspars with an anorthite content of less than 48 per cent. into the following groups³:—0-15 per cent. An., 15-22 per cent. An., 22-33 per cent. An., 33-36 per cent. An., 36-52 per cent. An., 42-49 per cent. An. It should be borne in mind, however, that a very slight potash content produces a marked depression in the refractive indices of the feldspars and determination, by this method, of plagioclases with an appreciable potash content will, therefore, result in the assignment of anorthite values lower than the true values.

In the material investigated by the author it was possible to apply this method of determination to the feldspars of the quartz-bearing hybrid rocks of the Salingyi complex in which the determinations were invariably concordant with the results of Fedoroff determination. In these rocks, however, in common with the

¹ L. Duparc and M. Reinhard, *loc. cit.*, pp. 140-141 and K. Chudoba, (trans. W. Q. Kennedy). 'The Determination of the Feldspars in Thin Section', London (1933), pp. 20-23.

² A. Rittmann, *loc. cit.*, and K. Chudoba, *loc. cit.* pp. 38-61.

³ For details see Duparc and Reinhard, *loc. cit.*

other rocks of this region, the paucity of potash is a remarkable feature which is emphasised both by the analytical results and the rarity of potash-bearing minerals. It may well be, therefore, that the degree of concordance between the Becke and Fedoroff determinations made by me is greater than can normally be expected.

On account of its limitations, both as regards its applicability, which is restricted to those rocks in which both feldspar and quartz are sufficiently abundant to furnish the two minerals in contact in all the required orientations, and as regards sensitiveness, this method is certainly no effective substitute for Fedoroff determination. In favourable cases, however, it is a useful aid to the working petrologist who requires a rapid and approximate method of determination which is independent of elaborate and expensive instruments.

A study of text figure 28 showing the variation of the optical angle in the plagioclase feldspars, at once reveals that the value of

The determinative value of the optical axial angle. $2V$, unless it be less than -82° , is not itself a determinative property, since the other values of $2V$ are common to feldspars of more than one composition. When, however, from other criteria such as refractive index or extinction values, the approximate composition of the feldspar is known, the value of $2V$ becomes of determinative value. As in the case of the refractive index, however, it is a value which is strongly influenced by a slight potash content and may therefore lead to erroneous conclusions.

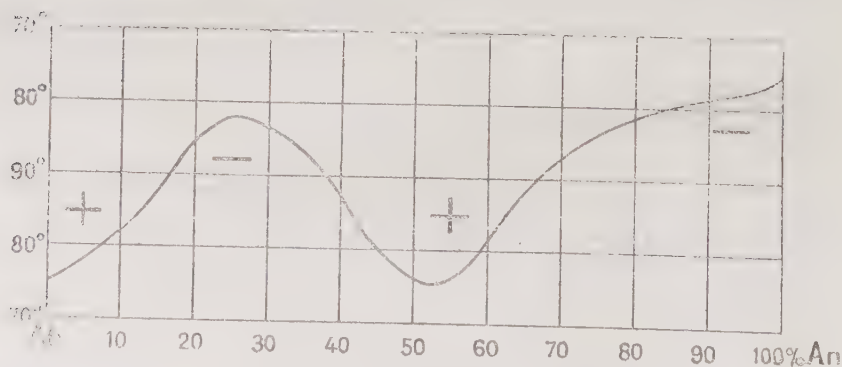


FIG. 28.—Showing the variation of the optic axial angle ($2V$) in members of the plagioclase series, after M. Reinhard.

In the course of my investigations by the Fedoroff method $2V$ was determined as an independent value in all cases in which it was possible to orient on the Universal stage the optic axial plane and at least one of the optic axes. In 99 of the 108 cases in which this was possible the anorthite value indicated by the magnitude and sign of the optic angle was within 5 per cent. of that obtained by Fedoroff's determination. The magnitude of the discrepancies occurring in the remaining 9 cases is shown by the following table:—

TABLE 9.—*Variations between the empirical and observed values of $2V$ in 9 feldspars.*

	Per cent. An. on the basis of Fedoroff determination.	Empirical value of $2V$ (Reinhard ¹).	Observed value of $2V$.	Per cent. An. on the basis of the observed value of $2V$.
(1) . . .	5	78	86	15
(2) . . .	5	78	88	16
(3) . . .	35	—86	—82*	25
(4) . . .	35	—86	—83	25
(5) . . .	45	80	90	38
(6) . . .	45	80	90	38
(7) . . .	60	82	90	66
(8) . . .	75	—85	90	66
(9) . . .	95	—77	—80	85

* In this instance both optic axes were orientable.

In examples 3, 4, 8 and 9 of the above table in which the variations between the empirical and observed values of $2V$ are only 4° , 3° , 5° and 3° respectively, the deviation is considered to be within the limits of experimental error even in example 3 in which both optic axes were orientable and in the stereographic projection of which the pole of na lay midway between the poles of the optic axes. In the other examples, in which the discrepancy between the empirical and observed values of $2V$ is eight degrees or more, it is greater than the degree of experimental error. In these cases the discrepancies may be due to small percentages of potash in the composition of the feldspars, which it is considered have but a slight influence on the *position* of the indicatrix (*vide* page 245 *supra*), but in view of the depression of the refractive indices, which, however, are not depressed by proportional amounts, must produce an appreciable alteration in its *form*. Insufficient systematic work

¹ M. Reinhard, *loc. cit.*, p. 109.

has been done on this problem to enable reliable conclusions or even useful hypotheses to be formulated on this question.

It is considered that the determination of $2V$ is a useful adjunct to determinations by the Fedoroff method, as in the course of determination by this method its magnitude is very easily ascertainable by direct readings in cases in which the optic axial plane is orientable on the Universal stage, and it is of value in affording a discriminative criterion in cases in which a morphological pole obtained by Fedoroff determination can be interpreted in more than one quadrant of the determinative stereogram (*vide* page 223 *supra*). Apart, however, from its determination in conjunction with determination by the Fedoroff method, there is little to be said in favour of the use of $2V$ as a determinative criterion. In the first place, the results in the absence of other determinative data, are ambiguous and in the second, its accurate determination by methods other than the use of the Universal stage is a more laborious and time-consuming process than Fedoroff determination, while the results obtainable by the two methods are not of commensurate value.

The so-called 'Zone method'¹ of determination of feldspars may be compared with the classical method of their determination by

The Zone method. means of the extinction value of oriented sections. The application of the latter method is contingent on the accidental occurrence in the thin section of plagioclase crystals with the required orientation, but in the zone method the desired orientation is imparted to the crystal by the use of the three axes N, H and K^2 of the Universal stage, and the extinction determined by rotation about the microscope axes (M).

This method was employed by the author in 51 cases, either for the determination of the composition of small zones in zoned phenocrysts or for determination of the twinning law in the case of small lamellæ in microlites which were too small for determination by the Fedoroff method, but in the 51 cases referred to the composition of at least one zone or lamella was determined by the Fedoroff method. The Zone method was also employed in a few cases for the determination of the composition of microlites which were too small to permit the determination of even one lamella by the Fedoroff method.

¹ A. Rittmann, *loc. cit.* and K. Chudoba, (trans. W. Q. Kennedy) *loc. cit.*

² *Vide* M. Reinhard, *loc. cit.*, p. 31.

In 41 of the 51 cases in which Fedoroff determinations were also made, and in which, therefore, a comparison of the results obtained by the two methods is possible, the anorthite value assigned on the basis of the Zone method was within 5 per cent. of that determined by the Fedoroff method. The magnitude of the discrepancy in the remaining ten examples is shown by the following table:—

TABLE 10.—*Variations between the results of Fedoroff determinations and determinations by the 'Zone method'.*

Per cent. An. on the basis of Fedoroff determination.	Per cent. An. on the basis of determination by the Zone method.
40	47
45	53
60	67
60	68
70	76
75	82
80	90
85	90 (95 in second lamella).
90	79
90	94(98 in second lamella).

Discrepancies of this magnitude will probably not be regarded as serious and the method does not lack exponents who contend that the slight inaccuracies which may result from determination by this method are more than compensated for by the time saved by the curtailed procedure involved. To this thesis I do not subscribe and wish to emphasise that, in the 51 examples cited above, every possible advantage was given to the Zone method by the previous determination by the Fedoroff method of at least one lamella or zone in each felspar. Not only, therefore, were the morphological directions to which the extinction values were referred, unequivocally established, but it was known also from the coincidence of the morphological poles with the curves of the determinative stereograms that these morphological directions were correctly oriented on the Universal stage. The importance of both these checks cannot be too strongly emphasised, and the danger of the 'Zone method' is not that inaccuracies of the order of magnitude of the above discrepancies may result, but that much greater

inaccuracies may result either from a mistaken identification of morphological directions or probably more frequently from a lack of precision in their orientation. In the case of the Fedoroff method, the worker's attention is drawn to any lack of precision in the orientation of either optical or morphological elements by features which are clearly visible from the stereographic projection. If, for instance, the optical symmetry elements do not lie 90° apart, their orientation on the Universal stage is repeated and checked. Again, if a morphological pole does not approximate to a curve of the determinative stereogram its orientation is also repeated and checked. If it is still found that the pole does not approximate within the usual limits of error to the curves, the case is investigated further and if no explanation is forthcoming the determination is rejected when making the statistical analyses. In the case of uncontrolled determination by the 'Zone method', however, there is no possible check on the result. A value is obtained for the extinction, which by reference to the appropriate curves will give a seemingly precise value for the anorthite content. A slight lack of precision in the orientation of the morphological directions will produce very inaccurate results, but since the value of the extinction obtained will in the great majority of cases be a possible value it will be accepted without question and the investigator will proceed in blissful ignorance of his error. The morphological directions to which extinction values are referred are either composition planes or cleavage and the directions which come most frequently in question are (010), (001) and the pericline composition plane. In albite-rich plagioclases the directions (010) and (001) are readily distinguishable on optical grounds¹ but the same criteria are not applicable to anorthite-rich members of the series, a fact which is not sufficiently emphasised in the descriptions of the method. The error in the computation of the anorthite value arising from the confusion of (010) with (001) in the basic members of the series may vary from 10 to 30 per cent., but the result obtained will not be so absurd as to warn the investigator of his error. Confusion of the pericline composition plane with (001) is a more frequent source of danger which may lead to errors, which although not so great as those arising from the confusion of (001) and (010) are nevertheless serious, while the unreliability of the pericline composition plane itself, even when correctly identified, has already been referred to.

¹ See K. Chudoba, (trans. W. Q. Kennedy), pp. 43-44.

As regards the alleged economy in time effected by the use of the method, it should be observed that this is realised only in ideal cases in which both (010) and (001) are recognisable and orientable on the Fedoroff stage and the extinction perpendicular to (001)/(010) is directly determinable. In other cases, in which it is necessary to determine a whole series of extinctions in the zone perpendicular to (010) in order to ensure that the maximum extinction has in fact been determined, the economy in time as compared with the Fedoroff method is greatly reduced if not, indeed, entirely eliminated.

For the reasons stated, the 'Zone method' is not regarded as an effective substitute for determination by the Fedoroff method. In the hands of the experienced investigator who realises its limitations it is a useful adjunct to the Fedoroff method, for the determination of small zones or lamellæ which are too small for complete Fedoroff determination but, like all short cuts, it is beset with pit-falls, so much so that its use by observers who have not served a long apprenticeship in the Fedoroff method is deprecated. Judging by the author's own experience, however, those who have served such an apprenticeship will no longer wish to use the 'Zone method' except in cases in which lamellæ or zones are too small to permit their determination by the Fedoroff method. So great, in fact, is my own distrust of the method that I would hesitate to base important conclusions upon it except in feldspars in which at least one lamella or zone has been determined by the Fedoroff method.

CHAPTER IX.

THE DETERMINATION OF THE MAFITES BY THE FEDOROFF METHOD.

In addition to its use for the determination of the feldspars, the Fedoroff stage was also employed for the determination of amphiboles, rhombic and monoclinic pyroxenes and minerals of the olivine group. In view of their higher symmetry, the scope of the Fedoroff method is more restricted in the case of these minerals than in the case of the feldspars. In the plagioclase feldspars and other triclinic minerals the indicatrix has complete freedom of orientation and consequently the determination of the orientation in its dependence on chemical composition teaches us more than in the case of minerals in which its freedom of orientation is restricted. In the monoclinic system, one of the axes of the indicatrix is normal to the crystallographic symmetry plane and the other two occupy varying positions in the symmetry plane itself. In the case of monoclinic minerals, therefore, the function of the Fedoroff method is the determination of the orientation of these axes in the symmetry plane itself, which, if the dependence of their orientation on chemical composition is known, is of determinative value. Another function of the Fedoroff method in connection with monoclinic minerals is the determination of the optic axial angle. In the rhombic system, the orientation of the indicatrix is still more restricted, and the three axes of the triaxial ellipsoid coincide with the three crystallographic axes. In minerals belonging to this system, therefore, the use of the Fedoroff method for determinative purposes is restricted to the determination of the optic axial angle. In both monoclinic and rhombic minerals, however, the method has proved of much value for the elucidation of morphological characteristics which could have been interpreted by other methods of optical investigation only under the most favourable conditions.

In view of their higher refringence and birefringence, and in the case of some amphiboles, their strong absorption, the accuracy which can be expected in the case of these minerals is less than in the case of the feldspars. It is considered, however, that the degree

of accuracy is greater than that obtainable by the classic method of the determination of the extinction of oriented sections, in which a slight absence of complete orientation often produces an appreciable vitiation of the extinction value. Quite apart from the determinative value of the Fedoroff method as applied to these minerals, I wish to record that a month devoted to their investigation by this method has taught me much more about their optics and morphology than a much longer period devoted to their investigation by the classic methods.

The apparatus employed for the determination of the mafites was the same as that used in the case of the feldspars except that hemispheres with a refractive index of 1.649 were employed instead of 1.557 in the case of the feldspars. As no abnormalities, such as the angles between the optical symmetry axes varying from 90° , were observed during measurement, it was found unnecessary to apply any correction for the slight deviations of the refractive indices of the minerals from that of the hemispheres. This does not apply to the determination of the optic axial angle, for which a correction should be applied, but as the refractive indices of the minerals were not accurately known, the uncorrected data are given.

Tabular summaries of the determinations of mafites made by this method are given in tables 11 to 13, below, and a brief discussion of a few other problems which were elucidated by this method will now be given.

Twinning in olivine is comparatively rare and only two examples were observed in the material studied by me. Both examples were investigated by the Fedoroff method and the composition plane determined. In the first example, in the olivine-gabbro (microslide 24178) projection on a plane perpendicular to $[001]$ yielded the co-ordinates $\phi 0^\circ$ and $\rho 49^\circ$ for the composition plane. By reference to Goldschmidt's tables¹, it was ascertained that this face approximates very closely (certainly within the limits of experimental error) with the face (021), the co-ordinates of which are $\phi 0^\circ$ and $\rho 49^\circ 33'$. (021) is a common face in olivine but as far as I can ascertain has not previously been identified as a composition plane.

¹ V. Goldschmidt, 'Krystallographische Winkeltabellen' Berlin, (1897), pp. 251-252.

TABLE 11.—*Minerals of the Amphibole group investigated by the Fedoroff method.*

Rock.	2V.	$n\gamma \wedge C$.	$n\gamma$ - na .	Pleochroism.	REMARKS.
Olivine-gabbro	—84	18	..	pale brown (nx) greenish-brown (n β) olive-green (n γ)	Twined on (100).
Do.	—84	14	..	pale yellowish-brown (nx) pale green (n β) bluish-green (n γ)	
Gabbro	—78	16	..	pale yellowish-brown (nx) pale green (n β) bluish-green (n γ)	
Do.	—86	15	..	pale yellowish-brown (nx) orange-brown (n β & n γ)	Irregularly but intimately intergrown in one instance.
Do.	—84	14	..	pale yellowish-brown (nx) brownish-green (n β) green (n γ)	
Do.	—84	17	0.022	pale green (nx) brownish-green (n β & n γ)	
Do.	—84	17	0.019	pale yellowish-brown (nx) brown (n β) deep brown (n γ)	
Hybrid rock	—17	21	..	pale brownish-green (nx) dark blue (n β) deep greenish-blue (n γ)	
Andesite	—72	9	}	golden-brown (nx) nigger-brown (n β) olive-green (n γ)	
Hornblende granuloite . .	—72 —89	7 17½	..	colourless	
Do.	+89	..	..	colourless	
Do.	—86	..	..	colourless	

TABLE 12.—*Minerals of the Pyroxene group investigated by the Fedoroff method.*

Rock.	2V.	$n\gamma\wedge C$.	$n\gamma-n\alpha$.	Remarks.	Composition (<i>vide</i> Winchell).
Basalt . .	61	40	0.025	Twinned on (100)	60-70 per cent. diopside in the diopside-hedenbergite series.
Do. . .	..	43		Twinned on (100).	
Do. . .	..	41		Twinned on (100)	
Do. . .	58	..	0.027	..	70-80 per cent. diopside in the diopside-hedenbergite series.
Do. . .	58	43			
Do. . .	59	43			
Gabbro . .	60	45	0.025	..	60-70 per cent. diopside in the diopside-hedenbergite series.
Do. . .	..	41			
Olivine-gabbro .	60	41	0.026	..	70-80 per cent. diopside in the diopside-hedenbergite series.
Do. . .	58	40		..	
Do. . .	58	40		Twinned on (100)	
Andesite . .	55	39	no section of maximum birefringence.	slightly pleochroic from very pale green ($n\alpha$) to equally pale brownish-green $n\gamma$).	80-90 per cent. diopside in the clinoenstatite-diopside series.
Do. . .	55	40			
Do. . .	57	..			
Do. . .	54	..			
Diabase . .	53	..	0.025	..	70-80 per cent. diopside in the clinoenstatite-diopside series.
Do. . .	53	..			
Do. . .	52	..			
Do. . .	..	37			
Do. . .	..	36			
Orthorhombic pyroxenes.					
Olivine-gabbro .	—70	..	0.013 to 0.015	Pleochroic from greyish-green ($n\gamma$) to pale pink ($n\alpha$).	Molecular percentage of Fe Si O_3 = 30 to 40.
Do. . .	—70	..			
Do. . .	—74	..			
Do. . .	—72	..			

TABLE 13.—*Minerals of the Olivine group investigated by the Fedoroff method.*

Rock.	2V.	$n\alpha-n\gamma$.	Remarks.	Composition (<i>vide</i> Winchell).
Basalt . . .	—88	0.035	. . .	Molecular percentage of $\text{Fe}_2\text{SiO}_4 = 15$.
Do. . . .	90			
Do. . . .	—88			
Do. . . .	90			
Do. . . .	90			
Do. . . .	90	0.037	Twinned on (031)	Molecular percentage of $\text{Fe}_2\text{SiO}_4 = 15$ to 20.
Do. . . .	90			
Do. . . .	90			
Olivine-Gabbro .	—88	..		Molecular percentage of $\text{Fe}_2\text{SiO}_4 = 30$.
Do. . . .	—85	0.040	Twinned on (021)	
Do. . . .	—86			
Do. . . .	—84			
Do. . . .	—87	0.037	Vermicular inclusions of hematite on (100).	
Do. . . .	—86		Molecular percentage of $\text{Fe}_2\text{SiO}_4 = 20$.	

The second example, also of normal twinning, occurred in the Sonetaung basalt (micro-slide 24138) and is figured in text figure 29. This consists of two individuals (2) of similar orientation with a

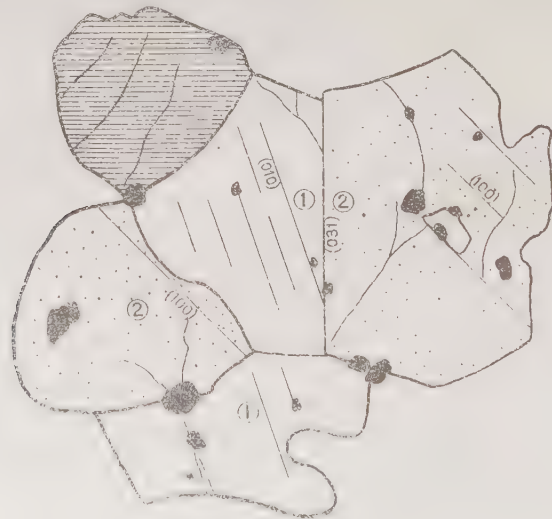


FIG. 29.—Illustrating an example of twinning in olivine.

second individual of other orientation between them (individual 1) and associated with another grain of different orientation shown at the top right hand corner of the figure. The contact between this individual and individual (1) is irregular and could not be oriented on the Fedoroff stage, and as no symmetry plane could be found between the two individuals, this is regarded as an irregular association of two grains and not as an example of twinning. The contact between individual (1) and individual (2) situated to the right of it is sharply defined and the composition plane corresponds to the optical symmetry plane between the two individuals. Projection on a plane perpendicular to [001] yielded the co-ordinates ϕ 0° and ρ 60° for this face. No face with these co-ordinates is given in Goldschmidt's tables¹, but by geometrical construction it was ascertained that this face coincides exactly with the face (031). The second individual (2) lying to the left of individual (1) is twinned with it according to the same law since its optical orientation is identical with that of the other individual (2), but in this case the composition plane is irregular. Twinning on (031) has been recorded in forsterite² but as far as I can ascertain has not previously been recorded in chrysolite. In this specimen, cleavage on (010) in individual (1) and on (100) in individual (2) was also determined.

In a specimen of olivine in micro-slide 24178, vermicular inclusions of hematite, which are figured in text figure 30 (page 288), were observed. On the ordinary microscope stage it was observable that they were oriented in one plane, but as this plane was oblique to the plane of the section it was impossible to identify it without the use of the Fedoroff stage. Orientation on the Fedoroff stage showed that this plane coincided with the crystallographic symmetry plane which is normal to $n\gamma$ and is, therefore, (100). This is a common direction of cleavage in olivine but in this instance cleavage was not developed. Similar vermicular inclusions in olivine were described by Dr. A. Harker³ in an anorthite-olivine-rock from Rum and were referred to by him as 'dendritic inclusions'. As cleavage is not developed in the example described above, the vermicular aggregates are not regarded as infiltrations but as being

¹ 'Kryystallographische Winkeltabellen,' Berlin, (1897).

² N. H. Winchell and A. N. Winchell, 'Elements of Optical Mineralogy', Part II, New York, (1927), p. 166.

³ A. Harker, 'Petrology for Students', Cambridge (1923), p. 93.

formed by the chemical disintegration of the solid solution with the separation of hematite (German, *Entmischung*).



FIG. 30.—Vermicular inclusions of hematite in olivine.

In the gabbro (micro-slide 24181), an interesting example of the association of two types of hornblende was observed. Predominantly of light green colour, a crystal of this mineral was seen to contain patches of brown hornblende with simultaneous extinction. This association was investigated by the help of the

Fedoroff stage and it was found that the orientation of the indicatrix and the optic angle of the two minerals was the same. The birefringence of the green variety is however slightly higher than that of the brown variety. The optical properties of the two minerals are as follows:—

	Green variety.	Brown variety.
2V	—84°	—84°
Extinction $n\gamma \wedge C$	17°	17°
$n\gamma - n\alpha$	0.022	0.019
Pleochroism	$n\alpha$ pale-green	$n\alpha$ yellowish-brown.
	$n\beta$ & $n\gamma$ brownish-green	$n\beta$ brown.
		$n\gamma$ slightly deeper brown.

These two minerals, therefore, furnish an interesting example of two members of an isomorphous series in which the *orientation* of the indicatrix (as evidenced by the identical extinction) and the *form* of the indicatrix (as evidenced by the identical optic angle) are the same, but in which the *magnitude* of the indicatrix is different, as indicated by the different birefringence.

BIBLIOGRAPHY.

- Alling, H. L. 'The Mineralogy of the Felspars', *Journ. Geol.*, XXIX, pp. 194-219, (1921).
- Baier, E. 'Lamellenbau und Entmischungsstruktur der Feldspate', *Zeitschr. Krist.*, LXXIII, pp. 465-560, (1930).
- Barber, C. T. 'Natural Gas Resources of Burma', *Mem. Geol. Surv. Ind.*, LXVI, pp. 1-172, (1935).
- Barth, T. W. F. 'Die Lage des "rhombischen Schnittes", bei sauren Plagioclasen', *Zeitschr. Krist.*, LXVIII, (1928). 'Permanent Changes in the Optical Orientation of Felspars Exposed to Heat', *Norsk Geologisk Tidsskrift*, XII, pp. 57-72, (1931).
- Bastin, E. S. 'Chemical Composition as a Criterion in Identifying Metamorphosed Sediments', *Journ. Geol.*, XVII, pp. 445-472, (1909).
- Berman, H. See Larsen, E. S.
- Bond, W. N. 'The Perfection of Crystal Laminae', *Phil. Mag.*, Ser. VII, XVI, pp. 410-422, (1933).
- Buerger, M. J. 'The Non-existence of a Regular Secondary Structure in Crystals', *Zeitschr. Krist.*, LXXXIX, (1934).
- Burri, C. und Huber, H. 'Geologie und Petrographie des jungvulkanischen Gebietes am Lower Chindwin (Upper Burma)', *Schweiz. Min. Petr. Mitt.*, XII, pp. 286-343, (1932). 'Grundzüge der Geologie von Burma mit besonderer Berücksichtigung des jungen Vulkanismus', *Zeitschr. Vulkan.*, XV, pp. 153-179, (1933).
- Chelius, C. 'Das Granitmassiv des Melibocus und seine Ganggesteine', *Notizblatt des Vereins für Erdkunde und Grossherzogl. Geol. Landesanstalt zu Darmstadt*, IV. Folge, 13. Heft, pp. 1-13, (1892).
- Chhibber, H. L. 'The Geology of Burma', London, (1934). See also Pinfold, E. S.
- Chudoba, K. (trans. Kennedy, W. Q.). 'The Determination of the Felspars in Thin Section', London, (1903).
- Cross, W., Iddings, J. P., Pirsson, L. V. and Washington, H. S. 'Quantitative Classification of Igneous Rocks' London, (1903).
- Cotter, G. de P. 'The Geotectonics of the Tertiary Irrawaddi Basin', *Journ. As. Soc. Beng.*, N. S., XIV, pp. 409-420, (1918).
- Coulson, A. L. 'On the Zoning and Difference of Composition of Twinned Plagioclase Felspars in Certain Rocks from Sirohi State, Rajputana', *Rec. Geol. Surv. Ind.*, pp. 164-171, (1931).
- Dalton, L. V. 'The Geology of Burma.' *Quart. Journ. Geol. Soc.*, LXIV, p. 604, (1908).
- Day, A. E. See Pinfold, E. S.

- Duparo, L. et Reinhard, M. 'La Détermination des Plagioclases dans les Coupes Minces', *Mém. Soc. de Physique et d'Histoire Naturelle de Genève*, XL, (1924).
- Eckermann, von H. 'The Rocks and Contact Minerals of Tennberg', *Geol. Foren. Stockholm*, (1923), pp. 465-537.
- Favre, G. See Sigg, H.
- Fenner, C. N. 'The Katmai Magmatic Province', *Journ. Geol.*, XXXIV, pp. 673-772, (1926).
- Fermor, Sir L. L. and Fox, C. S. 'The Deccan Trap Flows of Linga, Chhindwara district, Central Provinces', *Rec. Geol. Surv. Ind.*, XLVII, (1916).
- Fermor, Sir L. L. 'On the Basaltic Lavas Penetrated by the Deep Boring for Coal at Bhusawal, Bombay Presidency', *ibid.*, LVIII, (1925).
- Goldschmidt, V. 'Krystallographische Winkeltabellen', Berlin, (1897).
- Grimes, G. E. 'Geology of Parts of Myingyan, Magwe and Pakokku districts, Burma', *Mem. Geol. Surv. Ind.*, XXVIII, (1898).
- Harker, A. 'The Tertiary Igneous Rocks of Skye', *Mem. Geol. Surv. G. B.*, (1904).
- Harker, A. 'Natural History of Igneous Rocks', London, (1909). 'Petrology for Students', Cambridge, (1923).
- Harloff, C. 'Zonal Structure in Plagioclases', *Leidsche Geol. Mededeel.*, II, pp. 100-113, (1927).
- Heide, F. See Mügge, O.
- Homma, F. 'Ueber das Ergebnis von Messungen an zonaren Plagioklasen aus Andesiten mit Hilfe des Universaldrehtisches', *Schweiz. Min. Petr. Mitt.*, XII, pp. 345-351, (1932).
- Huber, H. See Burri, C.
- Iddings, J. P. 'Igneous Rocks', New York, (1909).
- James, R. W. 'The Intensities of X-ray Spectra and the Imperfections of Crystals', *Zeitschr. Krist.*, LXXXIX, pp. 295-309, (1934).
- Kalb, G. 'Typische vierseitige Vizinalpyramiden auf parallelkantigen viereckigen Grundflächen holödrischer Kristalle', *Zeitschr. Krist.*, LXXIII, pp. 266-269, (1930). 'Bermerkungen über Vizinalerscheinungen', *ibid.*, LXXXVI, pp. 1-7. 'Die Bedeutung der Vizinalerscheinungen für die Bestimmung der Symmetrie und Formenentwicklung der Kristallarten', *ibid.*, LXXXIX, pp. 400-409, (1934).
- Kelterborn, P. 'Einige Notizen über die Gesteine des jungvulkanischen Gebietes am Lower Chindwin, Upper-Burma', *Eclogae geologicae Helvetiae*, XIX, pp. 352-359, (1925).
- Klemm, G. 'Petrographische Mitteilungen aus dem Odenwald', *Notizblatt des Vereins für Erdkunde und der Hessischen Geol. Landesanstalt zu Darmstadt*, V. Folge, IX, pp. 104-117, (1926).
- Larsen, E. S. and Berman, H. 'The Microscopic Determination of the Non-opaque Minerals', *U. S. Geol. Surv.*, Bull. DCCCXLVIII, (1934).
- La Touche, T. H. D. 'Geology of the Northern Shan States', *Mem. Geol. Surv. Ind.*, XXXIX, (1913).
- Lepper, G. W. 'An Outline of the Geology of the Oil Bearing Regions of Burma and of Assam-Arakan', World Petroleum Congress London, (1933), preprint No. 168, pp. 1-10.

- MacGregor, A. G. 'Clouded Felspars and Thermal Metamorphism', *Min. Mag.*, XXII, pp. 524-538, (1931). 'Scottish Pyroxene-Granulite Hornfelses and Odenwald Beerbachites', *Geol. Mag.*, LXVIII, pp. 506-521, (1931).
- Manolescu, G. 'Ueber die Lage der morphologischen Bezugsrichtungen bei Plagioklasen und ihre Verwendbarkeit zur Bestimmung des Anorthitgehaltes', *Schweiz. Min. Petr. Mitt.*, XIV, pp. 452-463, (1934).
- Miers, Sir H. A. 'An Enquiry into the Variation of Angles observed in Crystals; especially of Potassium-alum and Ammonium-alum', *Phil. Trans. Roy. Soc.*, A, CCII, pp. 459-523, (1904). 'Mineralogy', London, (1929).
- Mügge, O. 'Ueber die Lage des rhombischen Schnittes im Anorthit und seine Benützung als geologisches Thermometer.' *Zeitschr. Krist.*, LXXV, pp. 337-344, (1930). 'Die Lage des "Rhombischen Schnittes" im Anorthit und die Benützung derartiger irrationaler Zusammensetzungsflächen von Kristallzwillingen als geologische Thermometer'. *Nachrichten der Gesellschaft der Wissenschaften zu Göttingen*, Fachgruppe IV, No. 3, pp. 219-226, (1930).
- Mügge, O. Und Heide, F. 'Einfache Schiebungen am Anorthit'. *Neues Jahrbuch f. Min.*, Bd. LXIV, Abt. A, pp. 163-170, (1931).
- Nikitin, W. W. 'Korrekturen und Vervollständigungen der Diagramme zur Bestimmung der Feldspate nach Fedorows Methode', *Min. Petr. Mitt.*, XLIV, (1933).
- Oldham, R. D. 'Explosion Craters in Lower Chindwin district, Burma', *Rec. Geol. Surv. Ind.*, XXIV, pp. 137-247, (1906).
- Paliuc, G. 'Untersuchungen der Plagioklase einiger tertiärer Ergussgesteine Siebenbürgens (Rumänien) mittelst der Universaldehrtischmethode', *Schweiz. Min. Petr. Mitt.*, XII, pp. 423-444, (1932).
- Pascoe, Sir E. H. 'The Oilfields of Burma', *Mem. Geol. Surv. Ind.*, XI, (1912).
- Penta, F. 'Studio petrographico della Pegmatite di Parchella (Cantazaro Calabria) Con osservazione sulle leggi di Geminazione di Periclino nell' Albite e nel Microclino', *Schweiz. Min. Petr. Mitt.*, XIII, pp. 187-203, (1933).
- Phemister, J. 'Zoning in Plagioclase Felspar' *Min. Mag.*, XXIII, pp. 541-545, (1934).
- Phillips, F. Coles. 'Pericline and Acline Twins in the Acid Plagioclases', *op. cit.* XXII, pp. 225-230, (1929-1930).
- Pinfold, E. S., Day, A. E., Stamp, L. D. and Chhibber, H. L. 'Late Tertiary Igneous Rocks of the Lower Chindwin Region, Burma', *Trans. Min. Geol. Ind.*, XXI, p. 115, (1927).
- Reinhard, M. 'Universal Drehtischmethoden', Basel pp. 1-119, (1931). See also Duparc, L.
- Rittmann, A. 'Etude pétrographique sur une Série de Roches des Gîtes Platinifères de l'Oural', Thesis No. 657, University of Geneva. 'Die Zonenmethode, ein Beitrag zur Methodik der Plagioklasbestimmung mit Hilfe des Theodolithisches', *Schweiz. Min. Petr. Mitt.*, IX, pp. 1-46, (1929).
- Sander, B. 'Gefügekunde der Gesteine', Vienna, (1930).
- Schmidt, E. 'Chemie der Erde', (1915).
- Sigg, H. et Favre, G. 'Quelques courbes nouvelles pour la détermination des Feldspaths par la méthode Fedoroff', *Bull. Soc. Vaudoise. Scien. Nat.*, LI, pp. 341-380, (1917).

- Spaenhauer, F. 'Die Andalusit-und Disthen-Vorkommen der Silvretta', *Schweiz. Min. Petr. Mitt.*, XIII, pp. 323-343, (1933). 'Ueber das Ergebnis von Messungen an synthetischen Plagioklasen mit Hilfe des Universaldrehtisches', *ibid.*, pp. 356-365.
- Stamp, L. D. See Pinfold, E. S.
- Tertsch, H. 'Der derzeitige Stand des Spaltbarkeitsproblems', *Centralbl. Min.* (1933), A., pp. 151-160.
- Tutton, A. E. H. 'Crystallography and Practical Crystal Measurement', London (1911).
- Vredenburg, E. 'A Zone-Fossil from Burma: *Ampullina* (*Megatlotus*) *Birmanica*', *Rec. Geol. Surv. Ind.*, LIII, pp. 359-369, (1922).
- Wadia, D. N. 'Palagonite-bearing Dolerite from Nagpur. Suggestion regarding the Nature and Origin of Palagonite', *op. cit.*, LVII, pp. 338-343, (1925).
- Washington, H. S. 'Chemical Analyses of Igneous Rocks' *U. S. Geol. Surv. Prof. Paper*, IC, (1917).
- Winchell, N. H. and Winchell, A. N. 'Elements of Optical Mineralogy', New York, (1927).
- Wülfing, E. A. *Sitzungsber. Heidelberg. Akad. Wiss. Math. Naturw. Kl.*, (1918), Abt. A., Abh. 13.
- Zwicky, F. 'On the Imperfections of Crystals', *Proc. Nat. Acad. Sci.*, XV, pp. 253-259, (1929).

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PART 1.

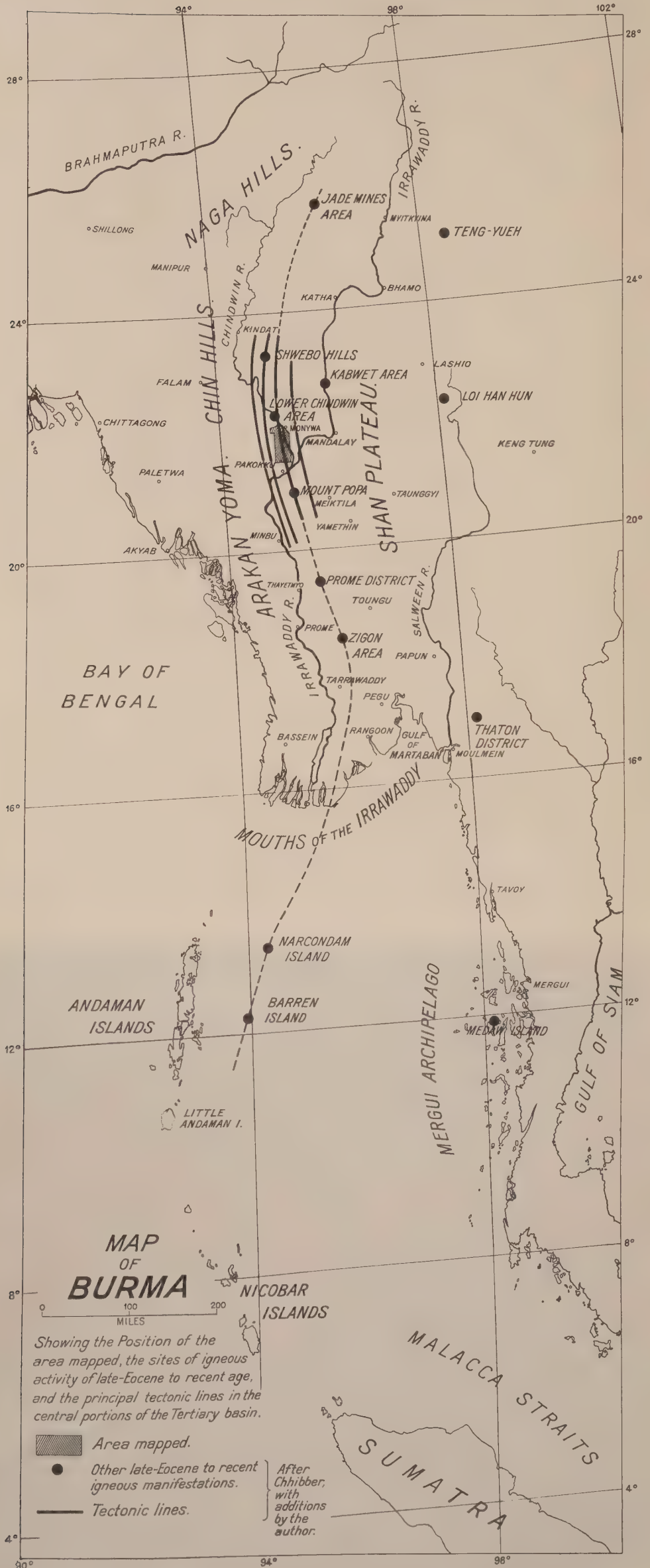
The Geology of South-eastern Mewar, Rajputana. By A. M. Heron, D.Sc. (Edin.),
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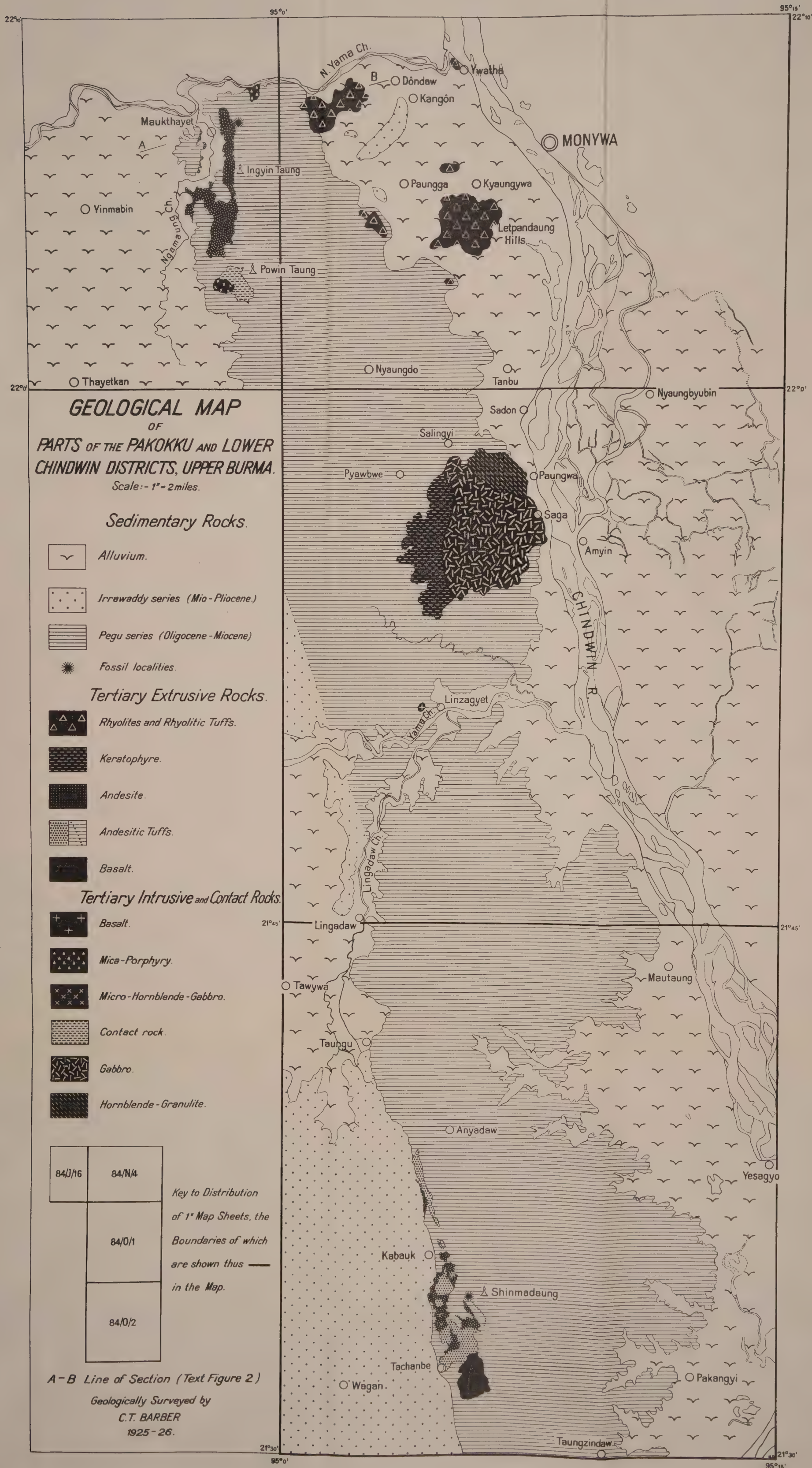
PART 2.

The Tertiary Igneous Rocks of the Pakokku District and the Salingyi Township
of the Lower Chindwin District, Burma, with special reference to the Deter-
mination of the Felspars by the Fedoroff Method. By C. T. Barber, M.Sc.,
F.G.S., M. Inst. P.T., *Assistant Superintendent, Geological Survey of India.*

GEOLOGICAL SURVEY OF INDIA.

Memoirs, Vol. LXVIII. Pl. 24.





GEOLOGICAL MAP OF PART OF THE PAKOKKU DISTRICT, UPPER BURMA.

Scale:- 1" = 1 mile.

Sedimentary Rocks.

Irrawaddy series
(Mio-Pliocene.)Pegu series
(Miocene & Oligocene)Zone of *Ampullina burmanica*

Dips

Tertiary Igneous Rocks.



Basalt



Compact Volcanic Ash.



Coarse



Fine



Bedded

Andesitic
Tuffs.

Andesite.



Diabase.

Country - Rock.

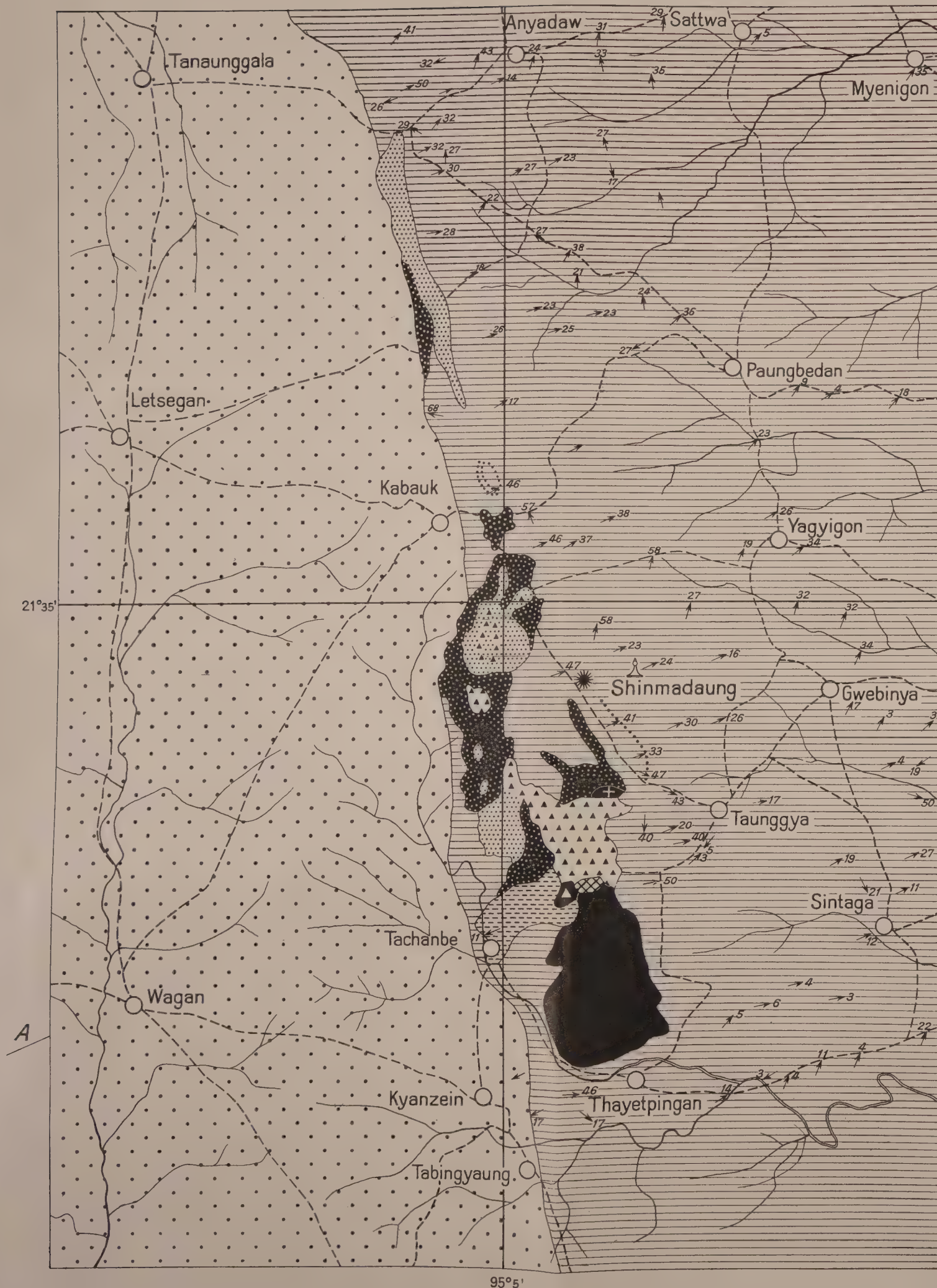
Boulders & Fragments of
Albite - Garnet - Gneiss.

A - B Line of Section (Text Figure 1)

Geologically Surveyed by

C.T. BARBER.

1925 - 26.



TAUNGNGIGYI
ONEBIN
SHINMADAUNG
TAUNGGLUGYI
TAUNGSHHE
TAUNGBET
TAUNGTHA
SONETAUNG



FIG. 1. PANORAMA OF THE SHINMADAUNG AREA, SEEN FROM A POINT TWO AND A HALF MILES WEST OF TACHANBE ($21^{\circ}32'$: $95^{\circ}5'$).



C. T. Barber, Photos.

G. S. I., Calcutta.

FIG. 2. PANORAMA OF THE LETPANDAUNG HILLS, SEEN FROM A POINT ONE MILE WEST OF THE VILLAGE OF YWASHE ($22^{\circ}6'$: $95^{\circ}9'$).



FIG. 1. TYPICAL TOPOGRAPHY OF THE PEGU SERIES, LOOKING NORTH FROM THE VILLAGE OF TAUNGZINDAW ($21^{\circ}30'$: $95^{\circ}10'$).



C. T. Barber, Photos.

G. S. I., Calcutta.

FIG. 2. INTERBEDDED TUFFS IN THE PEGU SERIES, ONE QUARTER OF A MILE NORTH OF THE VILLAGE OF TACHANBE ($21^{\circ}32'$: $95^{\circ}5'$).



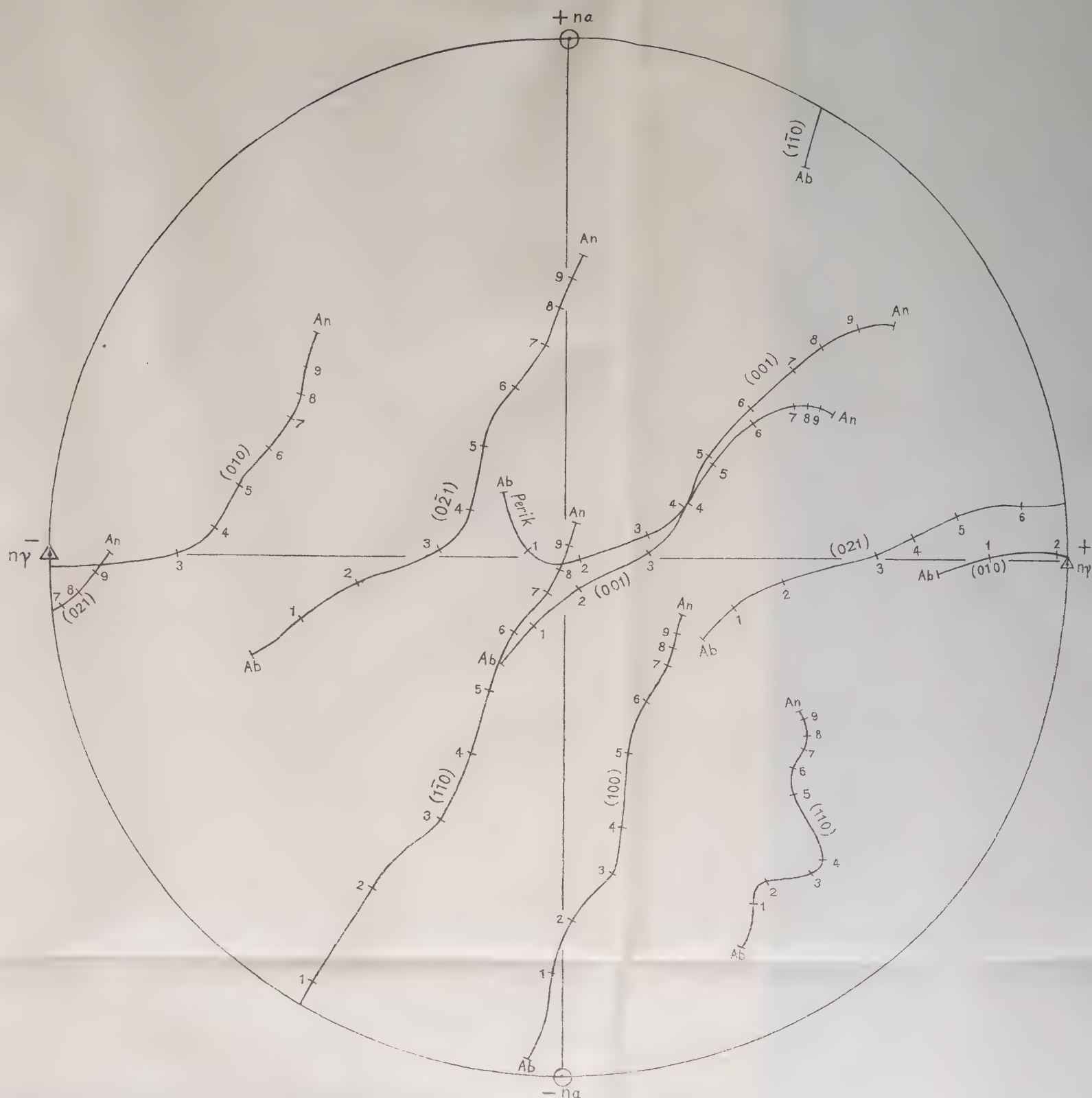
FIG. 1. AN INCLUSION OF QUARTZ-OLIGOCLEASE-BEARING ROCK IN THE GABBRO OF THE SALINGYI COMPLEX, TWO MILES SOUTH-WEST OF THE VILLAGE OF SAGA ($21^{\circ}57'$; $95^{\circ}8'$).



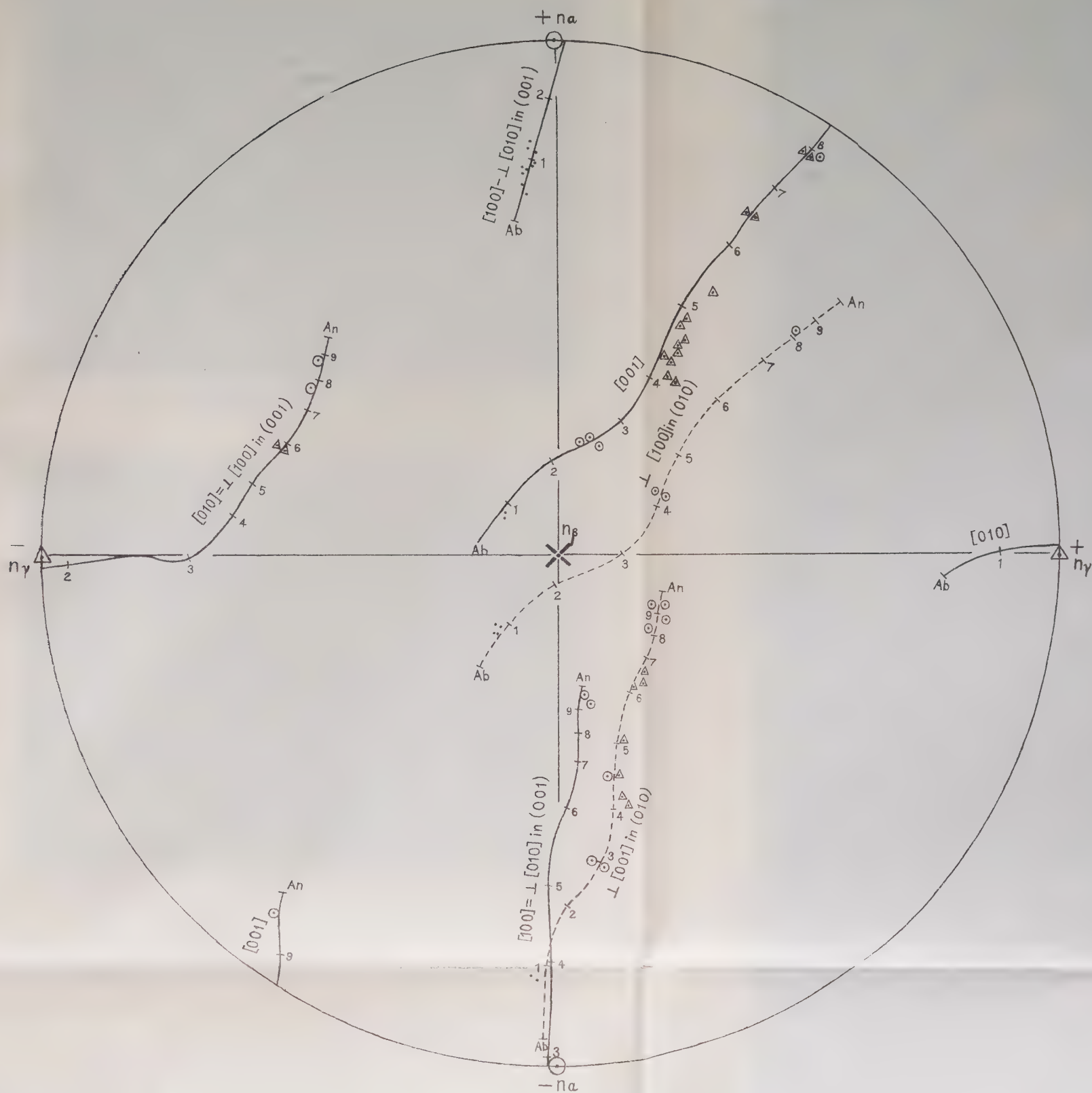
C. T. Barber, Photos.

G. S. I., Calcutta.

FIG. 2. ANCIENT CAVES IN THE MASSIVE SANDSTONE OF POWINTAUNG, LOWER CHINDWIN DISTRICT.



FEDOROFF-NIKITIN STEREOGRAMM, AFTER M. REINHARD.
Showing the migration of crystallographic poles (composition planes)
with reference to fixed optical vectors.



FEDOROFF-NIKITIN STEREOGRAMM, AFTER M. REINHARD.

Showing the migration of crystallographic poles (twin axes)
with reference to fixed optical vectors.

○ Poles of group A; △ Poles of group B; • Poles of group C.

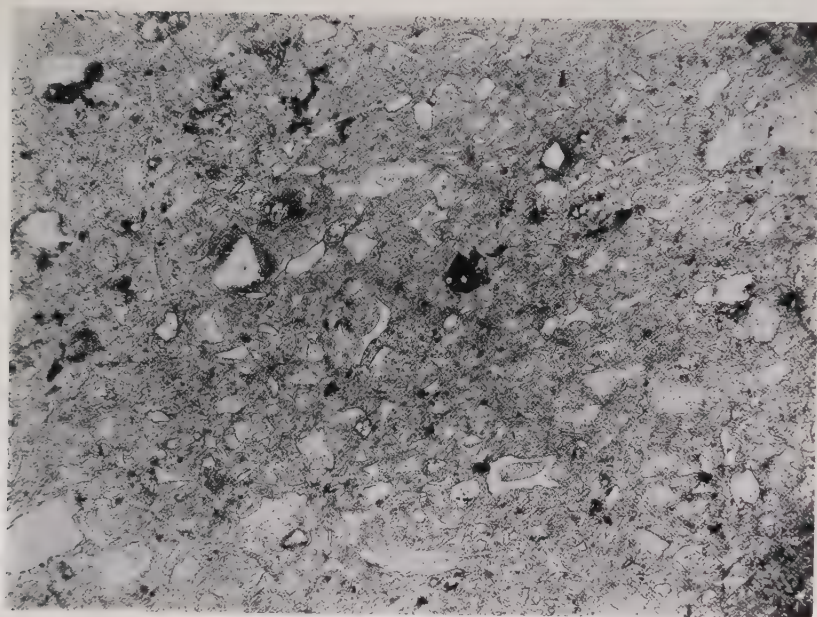
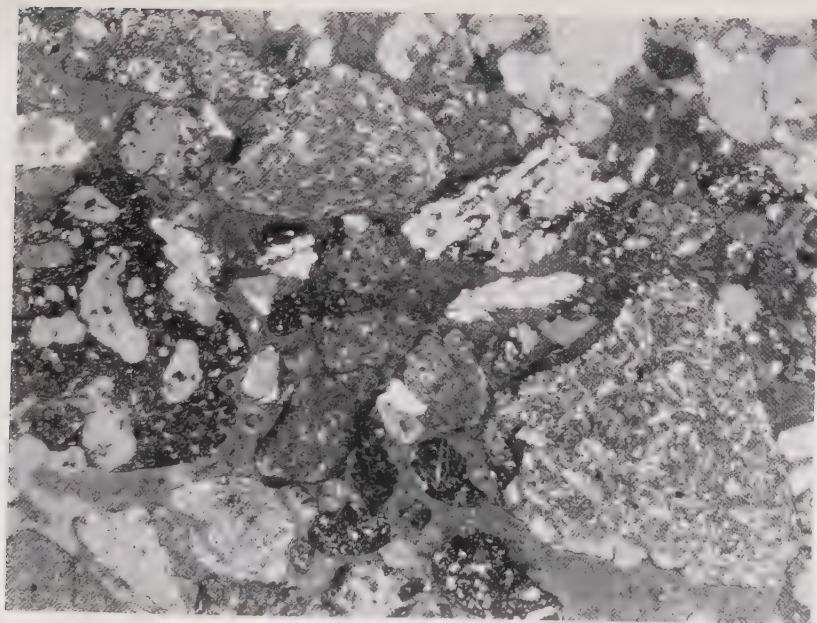


FIG. 1. VITROCLASTIC TUFF. Polarised light ($\times 22.5$).
Slide 24143.



Inst. Mineralogy, Basel, Photomicros.

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FIG. 2. LITHIC TUFF. Crossed nicols ($\times 12$).
Slide 24151.



FIG. 1. VARIOLITE. Polarised light ($\times 12$).
Slide 24173.



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FIG. 2. QUARTZ-OLIGOCLASE-BEARING-ROCK. Crossed nicols ($\times 12$).
Slide 24185.

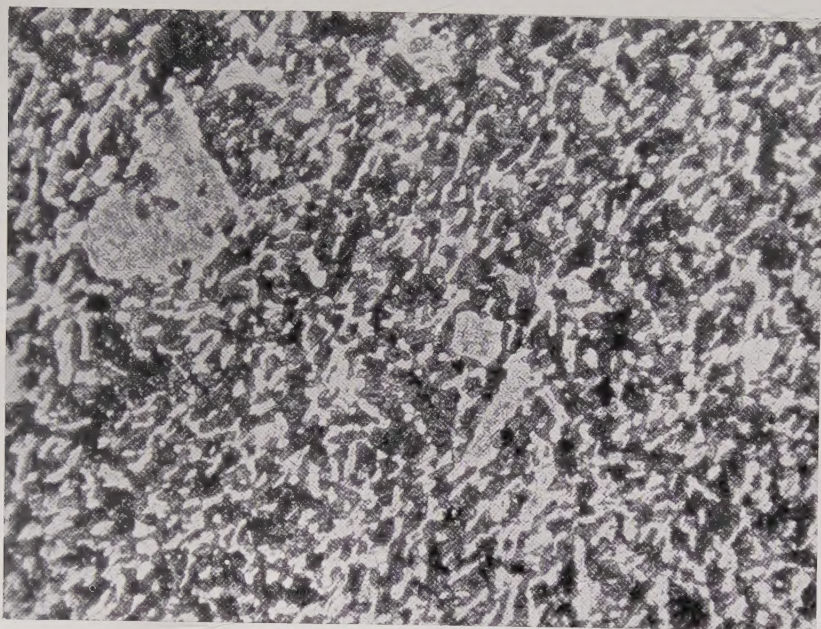
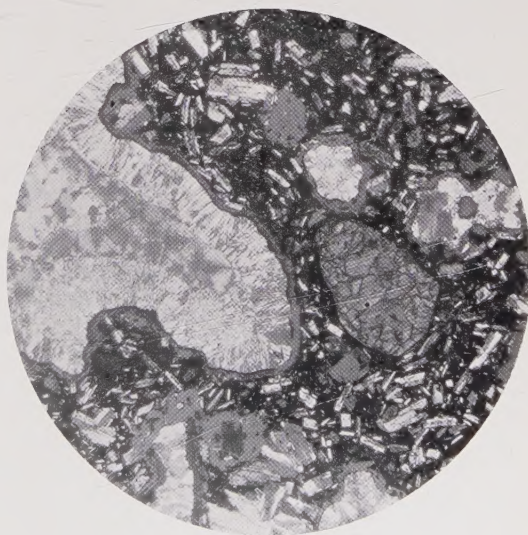


FIG. 1. HORNBLende-GRANULITE. Polarised light ($\times 25$).
Slide 24197.



Inst. Mineralogy, Basel, Photomicros.

FIG. 2. ANDESITE (MAUKTHAYET).
Crossed nicols ($\times 22.5$).
Slide 24214.



G. S. I., Calcutta.

FIG. 3. AMYGDALOIDAL ANDESITE.
Crossed nicols ($\times 9$).
Slide 24222.

CURRICULUM VITAE.

I, Cecil Thomas Barber, a British Subject, was born on the 22nd of November 1900, the son of Thomas Barber, School-Master, and his wife Alice Barber, nee Smout, both of whom are still living.

I received my early education at Redditch Secondary School, which I attended from October 1911 until July 1918.

In October 1918, I Matriculated in the University of Birmingham by means of the Senior Oxford Local Examination, which I successfully passed, with Second Class Honours in 1917. I studied in the University of Birmingham from October 1918 until July 1922 and attended the lectures and practical courses of Professor W. S. Boulton, Dr. (now Professor) L. J. Wills, and Dr. F. Raw, in Geology and Mineralogy; Professors P. Frankland and G. T. Morgan, and Doctors F. Challenger, J. E. Coates and C. E. Wood, in Chemistry, and Professor T. G. Madge-wick in Petroleum Mining.

In July 1921, I took my Bachelor of Science Degree in the University of Birmingham, with Geology and Mineralogy as Principal Subject, and Chemistry and Petroleum Mining as Subsidiary Subjects.

In July 1922, I took my Master of Science Degree in the University of Birmingham, in Geology and Mineralogy, and was awarded the Heslop Memorial Medal which is awarded annually by the University of Birmingham for the best dissertation accepted for the M.Sc. Degree. In 1922 also, I was elected a Fellow of the Geological Society of London.

In January 1923, I was appointed an Assistant Superintendent of the Geological Survey of India, and have held that post until the present time.

In 1928, I was elected to Membership of the Institution of Petroleum Technologists (London) and of the American Institute of Mining and Metallurgical Engineers (New York).

In October 1933, I Matriculated in the University of Basel, and for four Semesters have worked in the Institute of Mineralogy and Petrology under the Direction of Professor M. Reinhard.

In the University of Basel, I have attended the Lectures and Practical Courses of Professor M. Reinhard, Professor F. Jaeger, and Dr. A. Rittmann.

My previously published works are :—

“ Note on the Alleged Occurrence of Fossil Eggs at Yenangyaung, Upper Burma ”, *Rec. Geol. Surv. Ind.* LXII, (1929).

“ Some Aspects of Modern Oilfield Practice ” *ibid.* LXIII, (1930).

“ The Natural Gas Resources of Burma ”, *Mem. Geol. Surv. Ind.*, LXVI, Part 1, (1935).

